WIRELESS DIRECTION FINDING

⁂

A comprehensive manual on direction finding, dealing with wave propagation and D.F. theory in relation to modern Ground, Marine and Aircraft installations, with extensive bibliography

THIRD EDITION

R. KEEN

WIRELESS DIRECTION FINDING

By R. KEEN, B.Eng.

With a Foreword by T. L. Eckersley, F.R.S.

Third and Enlarged Edition

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AUTHOR'S NOTE TO THIRD EDITION

IN the preparation of a third edition of this book, a slight change of title has again been required, since the sections dealing with directional aerials for commercial wireless traffic have been omitted in order to make room for matter more directly concerned with Direction and Position Finding. This has been made necessary by the advances that have taken place during recent years in Marine and Aircraft Beacons, Aircraft Approach and Landing Apparatus, Automatic Direction Finders and in all kinds of Ground and Mobile Equipment.

The author's aim has been, as in previous editions, to make the book acceptable, not only to the engineering student, but also to the radio-telegraphist, the air pilot and the installing technician. For this reason the text is mainly descriptive. The Bibliography is believed to contain most of the worth-while literature on the subject and the frequent references to this section will be of value to those readers who require a more academic treatment. It also extends the use of the book to the research engineer who wishes to consult the original writings of as many authorities as possible on some particular branch of D.F. work. In many cases the reference further serves as due acknowledgment of a source of information.

Of the contributions by physicists, during recent years, to our knowledge of the Propagation and Reception of Electromagnetic Waves, it is probable that no work has been of more immediate value to Direction Finding than that of Mr. T. L. Eckersley. The author is therefore greatly honoured by Mr. Eckersley's having consented to write, in the form of a foreword, some notes on the relation of pure science to Wireless Navigation.

The author is also deeply grateful to many old and new friends for their help in the preparation of this edition, and acknowledgments to them and to the several Companies and Organizations, who have supplied data for the text and illustrations, will be found on another page.

R. KEEN.
Brentwood, July, 1938.

FOREWORD

EVERYTHING that the technician requires to know about the now well-established art of Radio Direction and Position Finding will be found most lucidly explained in the following chapters, and the author has asked me to add a few words on the scientific aspect of the work. The scientific side and the technical side really go hand in hand. The practical development has been greatly helped by the scientific investigation of wave propagation and, again, the science of radio propagation owes a great debt to the practical development of Direction Finders. To the union of the two, we owe, for instance, the discovery of the scattering of wireless waves, by fleeting ionic clouds in the " E " region of the ionosphere, which has such a profound effect on short wave Direction Finding. It is this scattering which probably also limits the ultimate accuracy of all types of Radio Direction Finding work, at distances where the wave reflected from the ionosphere is predominant.

Practical problems, linked with a curiosity as to why Radio Direction Finding accuracy compares so unfavourably with optical accuracy, have prompted the scientific analysis of this question and it is interesting to note that the use of the long electric waves, appropriate to wireless, has imposed a theoretical limit to the ultimate accuracy of the Direction Finder. The theoretical limit is similar to that of the resolving power of a microscope and it is known that two objects, separated by a distance of less that a wave length of the light with which they are illuminated, cannot be resolved. Similarly a Radio Direction Finder cannot distinguish between two transmitters that are less than a wave length apart. This is the ultimate theoretical limit of accuracy but, in practice, the deviations due to irregularities on the ground and in the ionosphere are far greater.

There are many other cases in which the Direction Finder has been of the greatest help in unravelling the complexities of radio transmission, and in particular we may mention various types of echo effect. Round the world echoes, which arrive in the opposite direction to the waves which traverse the normal, or short, Great Circle path, or those which come in the same direction, having encircled the world again after first passing the receiving station, can readily be distinguished by suitable Direction Finding devices. Other echoes, usually of shorter delay, have been traced, by the use of the D.F., to signals that have been scattered right out of the Great Circle path, and a development of the Direction Finder, which measures angles in the vertical plane, has been an invaluable help in checking the theory of this oblique form of transmission, and identifying the various rays which connect the sender and receiver.

In these and other ways, the practical and scientific developments have been of great mutual advantage, but the example of Radio Direction Finding is only one of the many in which pure science owes a great debt to industry and in which the industry, on the other hand, can only advance with scientific progress.

T. L. ECKERSLEY.

ACKNOWLEDGMENTS

IN the preparation of this new edition, help and encouragement have been received in varying degrees from so many quarters that it is no easy matter now to make the proper acknowledgments. Firstly, however, I wish to thank Mr. G. M. Wright, who helped so extensively with the work of the two earlier editions, for again reading the whole of the manuscript and for advice and criticism during this and subsequent stages. I am also greatly indebted to Mr. S. B. Smith for reading the proofs of Chapter 9, on the Ground D.F. Installation, and for his friendly interest in the book over a period of many years.

Part of my obligation to Mr. T. L. Eckersley has been mentioned in the preface but I have to thank him also for assistance on many other occasions, and also Mr. K. W. Tremellen for valuable help with Chapter 2 on Wave Propagation and for reading the manuscript of Chapter 10 on Short Wave D.F.

Other members of the Staff of Messrs. Marconi's Wireless Telegraph Company, Ltd., to whom I owe thanks, include Dr. G. F. Brett for data regarding the Cathode Ray Tube section of Chapter 16, Mr. R. J. Kemp for help with the same chapter and Mr. L. A. Sweny, Mr. N. H. Clough and Mr. F. P. Best, for reading the proofs of the Aircraft, Beacon Transmitter and Ship D.F. chapters respectively, also Mr. H. T. Sayer and Mr. J. M. Furnival for matter they kindly supplied for the Aircraft sections.

With regard to the early part of Chapter 14, dealing with Airport D.F. Organisation, I gratefully acknowledge the expert assistance of Mr. C. V. Lane; also of Squadron Leader G. E. Godsave, and Mr. R. J. Williamson for help with the latter part of the chapter which concerns the mobile D.F. Thanks are also due to Mr. F. Barton for reading the manuscript of Chapter 15, on Aircraft Approach and Landing Systems, to Dr. R. L. Smith-Rose and Mr. R. F. Barfield for reading the proofs of the chapters on Night Effect and The Adcock Aerial respectively and to Mr. W. T. Walder for information on Flying Instruments used in Chapters 13 and 15.

Mr. F. Addey has earned my deep gratitude by undertaking the complete revision of Chapter 14, on Nautical and Field Astronomy, including most of the examples, the necessity for which had arisen largely owing to changes in the arrangement of the data in the Abridged Nautical Almanac.

Whilst thus gladly acknowledging the assistance of these various experts, they must not be held responsible for inaccuracies that may be found, since much of the text has been subjected to modification and re-arrangement in the later stages of the work.

I am most grateful to the Managements of the undermentioned Companies and Organisations for the supply of information regarding D.F. Apparatus and Systems, for the originals of the illustrations which are only briefly acknowledged in the captions, and in many instances to Officials who have shown personal interest :—

> Messrs. : Federal Telegraph Company, New Jersey ; Imperial Airways Limited, London ; International Marine Radio Company, Ltd., London ; Lear Developments Inc., New York ; Marconi's Wireless Telegraph Company, Ltd., London ; R.C.A. Manufacturing Company Inc., New Jersey ; Radiomarine Corporation of America Inc., New York ; Standard Telephones and Cables, Ltd., London ; Telefunken Gesellschaft für Drahtlose Telegraphie, M.B.H., Berlin.

I acknowledge, with thanks, much information and several illustrations taken, by permission, from the U.S. Bureau of Standards Journal of Research. I also thank The Controller of H.M. Stationery Office and The Hydrographer of the Navy for permission to reproduce matter from Stationery Office Publications and Admiralty Charts, which are acknowledged in the text or captions, Mr. R. S. Shipway for his careful reading of the final proofs and for many important corrections and finally, the staff of *The Wireless World* for their patience and co-operation.

I offer my apologies to any whose names have been accidentally omitted from the above list, and to the original author or publisher of any illustration or subject matter that has not been properly acknowledged.

R.K.

WIRELESS DIRECTION FINDING

Numbers in brackets thus: (0815), (1906) refer to Bibliography Section. See further note on page 759.

CHAPTER I

INTRODUCTION

Directional Transmission. In looking back through the early history of the study of Electromagnetic Wave phenomena, it is found that attempts were made to obtain directional transmission long before the subject had any practical application for the purpose of telegraphic communication. The primitive transmitting apparatus used in these early investigations was capable of radiating only comparatively low power, and since the receiving devices were also of an insensitive nature, it appeared essential to adopt some means of concentrating the radiated power in the form of a beam directed towards the receiver. By this means it was hoped to avoid the losses which result from transmitting broadcast in all directions with equal intensity.

In an historical note in this introductory chapter, some of the outstanding experiments on directional transmission and reception during the last forty years have been briefly mentioned, and during this period wireless telegraphy has passed through the various stages from a laboratory experiment in practical physics to an almost universal and international method of communication of ever-increasing importance.

Directive Transmission and Reception. As the means of radiating greater amounts of power were developed and receivers were made more sensitive, it was found that communication could be carried out over distances up to many hundreds of miles with aerial systems which were only slightly directional in their properties, and so the urgency for beam transmission, for economic reasons and in order to obtain the desired range, became less apparent. With increasing powers it also became difficult to construct highly directive aerials.

It had, however, been realised for a long time that if wireless transmitters or receivers could be given accurate *directive* properties as, for example, a definite maximum radiating or receiving property in one direction and a definite minimum (or zero) radiating or receiving property in another direction, the scope of wireless communication could be extended and the position of a transmitting or receiving station could be found by purely wireless means.

It is these precise directive properties as applied to position finding and navigation rather than the merely directional properties given to a transmitter for economic reasons, which are chiefly dealt with in the ensuing chapters.

Comparison of Visual and Wireless Means of Direction and Position Finding. The operation of direction finding and navigation by wireless is closely allied to the visual means, and a comparison of the two methods indicates clearly the value of the latter, but also its limitations. Suppose that the noise from a passing aeroplane attracts our attention, and we notice that a machine of such and such a registered number is flying 500 feet high and that it is, at the moment, about a quarter of a mile north of us. All this information can be obtained from a comparatively rapid glance, and this is rendered possible owing to our eye-brain combination which interprets the effect of light reflected from the aeroplane and surrounding country, in the form of the information mentioned above.

Limitations of the Visual Method. Had the aeroplane been several miles distant, our attention would not have been attracted in the first place because we should not have heard the noise. Again, if the machine had been obscured by fog, all visual means of gaining information would have been ruled out. Wireless telegraphy has enabled *communication* to be carried out between aircraft, ships or shore stations when the distances are enormously greater than could possibly be spanned by any visual means. It was, however, in order that we might also get wireless *bearings* of ships and aircraft to replace the visual bearings that are no longer possible over these great distances that has stimulated the development of the wireless direction finder.

Propagation of Light and Wireless Waves. Both Light and Transmitted Wireless Energy are forms of vibration or wave motion in a medium known as the "ether," which pervades the whole of space. Both are normally propagated in straight lines with a velocity of approximately 186,000 miles, or 300×10^6 metres, per second. Light is made manifest to us because the speed of vibration of the ether corresponding to light of various colours is able to affect the eye-brain combination. We have, on the other hand, no sense capable of perceiving, even to the smallest degree, the existence of the relatively much slower vibrations in the ether which correspond to the transmission of what we term " wireless energy."

The way in which these waves are actually detected is by their conversion into some other form of energy such as sound, which can be perceived by a sense which we already possess, and it will be assumed that the reader already has some knowledge of how this conversion is achieved.

DIRECTION FINDING BY WIRELESS MEANS

Directive Reception. The Direction Finder (D.F.) is a type of wireless receiving station which, in virtue of the properties of a certain type of aerial system, makes it possible to find the horizontal angle of incidence of received signals relative to some standard, which is almost universally taken as the direction of true North. The process of taking the bearing of the distant station consists in rotating the directive aerial system until a certain alteration in the intensity of the signals indicates to us that the plane of the aerial system and the direction of incidence of the wireless signals bear some definite prearranged relation. The rotating portion of the system is calibrated from 0° to 360° set out in a clockwise direction, that is to say, from North, through East, South and West, so that the resulting angle will be measured off as a bearing in degrees East of North. This operation can be carried out no matter what distance the source of the signals is from the receiving station, so long as the signal intensity is great enough for aural reception.

Position Finding by Directive Reception. Just as distances judged by the naked eye are liable to serious errors owing to optical illusions, etc., so the distance of, say, a 200 W. aircraft transmitter judged by the strength of received signals is also only very roughly correct, although in both cases experience will bring a measure of accuracy.

Suppose, for instance, that the operator at a D.F. station at A in Fig. 1 observes the bearing of an aeroplane to be 61° East of North, then the machine must be somewhere on the line *Aa*, which is called a **position line.** From experience he might be able to estimate the distance as between 10 and 15 miles, but obviously it would be very unsatisfactory and

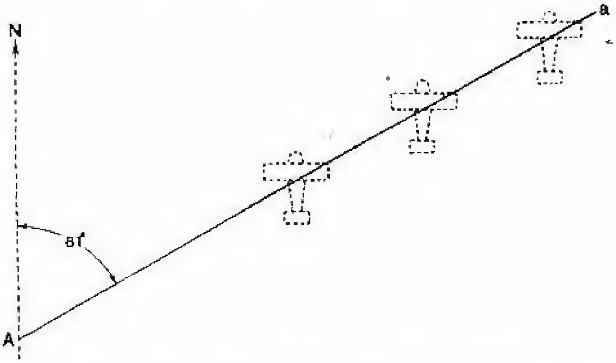

Fig. 1.—Direction Finding by a single D.F. Station at A.

dangerous, when requested by an aircraft for a position during fog, to use the true bearing and estimated distance in this way.

In practical position finding, therefore, it is usual to erect two or more D.F. stations and to employ the triangulation methods of ordinary surveying. Thus, in Fig. 2, if A and B are two D.F. stations and C is an aeroplane having a wireless installation, then if the directions of the incident waves at each of the D.F. stations be found relative to the direction of North, and if these directions are laid off on a map A*a* and B*b*, then the position of the aeroplane must be at the intersection of the two position lines. In Chapters 8 and 14 the subject is dealt with from a practical standpoint, and there is also introduced the important modification of the above methods when the directive receiver is located in the aeroplane or ship, as the case may be, enabling the observer on the mobile station to note the bearings of fixed transmitting stations and use them for navigational purposes.

Accuracy of the Wireless Direction Finder. The guaranteed limit of accuracy of a commercial direction finding installation is usually in the neighbourhood of 1° for a shore station and rather less than this, say 2°, in the case of a D.F. installed in a ship. Greater accuracy than this can be secured on a shore station if required, and, indeed, usually is secured over large sectors of the arc over which the station operates, but there are frequently a few residual errors, and an all round figure of 1° at the time of installation is all that is normally required. The accuracy with which the *position* of a wireless transmitter can be located by a number of D.F. stations, is discussed in Chapter 14.

It is difficult to obtain as high a degree of accuracy in a ship as on a shore D.F. station for a variety of reasons which are mentioned later, and, furthermore, the same standard is not required at sea. The principal function of the Direction Finder in a ship is to provide a check on the older-established methods of navigation, and to be of assistance to the navigator during thick weather, by providing him with relative bearings of certain wireless transmitting stations and wireless beacons, the positions of which are known. By this means he is often able to find or confirm his position after a long stretch of " dead reckoning."

The problem of aircraft wireless navigation is more difficult owing to the high speed of an aeroplane, but it is also more insistent since during bad visibility owing to fog, low clouds, snow or rain storms, no other means of navigation is available. The difficulties introduced by the very high speeds of aircraft are being met by the application of the cathode ray oscillograph for the instantaneous observation of bearings, and this will be referred to again in Chapter 16. The accuracy with which air liners and mail and freight aircraft are guided to their destinations is now well known, as is also the regularity with which they are able to follow their schedules between airports where a high standard of efficiency in wireless procedure exists.

Accuracy and Sensitivity. Accuracies of a quarter and a tenth of a degree are sometimes claimed, but these are usually laboratory figures and are not obtained day after day on commercial stations. Still more frequently it will be found that the claimant is confusing Accuracy with Sensitivity. It

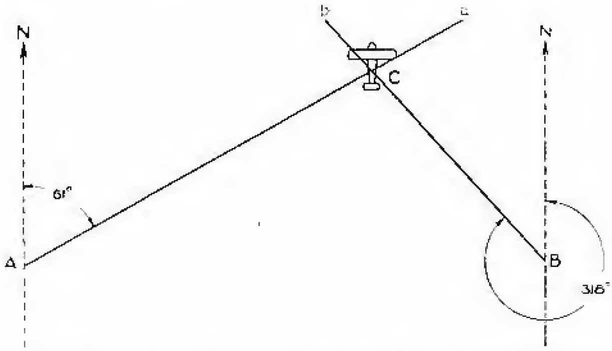

Fig. 2.—Position Finding by Directive Reception at two D.F. Stations A and B

is a comparatively straightforward matter to make a D.F., which, by careful attention to detail and thorough screening, will have so well defined a directive effect that *variations* of a quarter or a tenth of a degree can be detected in an observed bearing, but this is no criterion of the accuracy of the instrument as a direction finder. This depends on a very large number of other factors in addition to the precision of the apparatus used.

HISTORICAL NOTES

Although some of the methods adopted in the early days for directional transmission have no application in the modern direction finder, a short historical record is of interest, as it shows the development of the present-day apparatus. The early history of the subject is also dealt with in an editorial in *The Electrician* (0606) and by Bellini (1402).

Mirror Reflectors. Hertz, in his extremely important original researches, demonstrated the fact that both light and electromagnetic radiation were similar forms of energy by showing that they could both be reflected in the form of a beam by means of mirrors (9301). For the purpose of concentrating the transmitted electromagnetic wave motion, he made use of cylindrical parabolic mirrors about two metres high and one metre in width and obtained successful results, using a wave length of about two-thirds of a metre.

In later years when Marconi attacked the great problem of practical wireless communication, he also made successful use of copper parabolic mirrors and was enabled to detect, at a distance of two miles, the beam transmitted in this manner (9901), (2212).

Screening. Experiments were carried out in Germany by Zenneck in 1900 in connection with the screening of a vertical aerial in certain directions, by the erection of additional vertical wires (1501). From his own accounts of his work, it is fairly clear that Zenneck was on the verge of important discoveries regarding the properties of spaced aerials, but the experiments seem to have been discontinued after moderately promising results had been obtained.

In other countries work was being carried out along similar lines and led to the complete wire screen or reflector which superseded the mirror for this purpose.

Screen Reflectors. The employment of mirrors became impracticable as the length of the waves used was increased, it being necessary that the size of the mirror should at least be comparable with the dimensions of the wave length employed. (An optical mirror, for instance, of one centimetre in diameter is more than a hundred million times the dimensions of the greatest wave length it is required to reflect.) A number of inventors realised, however, that a satisfactory reflector could be formed of vertical wires, spaced about the transmitting aerial in the form of a parabolic screen and arranged so that the transmitting aerial was at the focus, or along the focal line of the cylindrical mirror so formed. Patents were granted to S. G. Brown in 1899 and to Lee de Forest in 1902 for inventions of this nature and modifications of this type of reflector are in use at the present day.

Horizontal, Inclined and Bent Aerials. From 1900 onwards, the attention of a number of experimenters has been turned to the use of aerials having a horizontal portion, and accounts were published by Galliot (0603), Kiebitz (1006), Marconi (0602), and a patent was applied for by de Forest in 1901 for a radiator having both vertical and horizontal limbs.

F. Braun, in 1902, obtained a degree of directional effect with a straight inclined aerial (0701), (0301), (0601), and the use of horizontal aerials close to the ground, for the same purpose, has been proposed by other workers, including Marconi, Zehnder (1208) and Kiebitz (1201 and 1210).

Fig. 3.—The Marconi "Inverted L" Aerial.

Of the above methods of obtaining directional transmission or reception, the one that had the greatest promise of wide commercial application, by the employment of a bent aerial, was the Marconi inverted L aerial, which is shown diagrammatically in Fig. 3. If the horizontal limb of such an aerial be made considerably longer than the vertical portion, the radiating (or receiving) property is found to be greatest in a direction opposite to that in which the horizontal limb is pointing (0609), (1106). In 1905, Marconi patented the combination of an inverted L transmitting aerial with a similar receiving aerial, claiming that very appreciable directional effects could be obtained in this manner. A further patent was taken out in 1906 for a method of direction finding in which a number of inverted L aerials were erected with the horizontal portions equally spaced in a radial manner about the receiving apparatus. On connecting the aerials in turn to the receiver, the one which gave the greatest signal intensity was assumed to be pointing away from the distant station, and hence the direction of the incident waves could be found approximately.

This type of aerial is still in common use, but in the case of the inverted L transmitting aerial, the directional properties have been somewhat eclipsed by the value of this particular form of construction as a means of obtaining an aerial of large capacity required for high-power long-wave transmitters.

A year later, in 1907, Scheller patented, in Germany, his "Course Setter" using the interlocked A/N signal and this equi-signal device was destined, a quarter of a century later, to be the underlying principle of certain approach and blind-landing systems for aeroplanes that are dealt with in subsequent chapters.

Spaced Aerials. The augury of accurate wireless direction and position finding may be said to date from the early investigations of the radiation of a system of two (or more) aerials, the currents in which bore definite phase and amplitude relations one with another. In such a case the received energy at any distant station is that due to the combined effect of both (or all) the transmitting aerials, and whilst in some directions these may assist one another and give a maximum of received energy, there may be other directions from which the effects neutralise one another and the reception is zero.

In Chapter 3 we shall investigate the way in which two spaced open aerials or a single closed loop aerial are affected by an incident wave and how such aerial systems come to have directive properties, but for the purpose of this brief historical survey it is enough to note that these properties exist, and, moreover, that they have a very important bearing on modern methods of direction finding.

The polar diagrams of radiation or reception (page 60) for a large number of conditions of spacing of aerials and phase differences of the respective aerial currents, are described by Zenneck (1501), Bellini (0906), L. H. Walter (1001), and a number of other writers.

As early as 1899, S. G. Brown claimed directive properties for a system of two vertical aerials, connected to the spark balls of an induction coil and spaced half a wave length apart. Such an arrangement was shown to have maximum radiating and receiving properties in the plane of the two aerials. Patents were also granted to M. R. Garcia and to Lee de Forest for inventions of a similar nature, and in 1903, A. Blondel suggested another arrangement of two spaced aerials to obtain the same directive results as S. G. Brown.

In 1902, the directive aerial system of S. G. Brown was adapted by J. Stone Stone for use as an actual direction finder, but since he proposed to rotate the two aerials, spaced half a wave length apart, about a vertical axis midway between them, the suggestion was scarcely a practical one on the wave lengths commonly used at that time. These difficulties prevented S. G. Brown or J. Stone Stone from realizing a practical direction finder, but their achievements may be said to have laid the foundation of the more modern systems.

In 1906, Prof. F. Braun (0601) described a method of obtaining a " heart-shaped polar diagram of radiation " (page 69) by means of three vertical aerials situated at the corners of an equilateral triangle and in which currents, bearing definite phase relations with one another, were produced by a method devised by N. Papalexi and L. Mandelstam (0605).

A scheme for avoiding the necessity of rotating the spaced aerials of S. G. Brown and others was introduced in 1907 by E. Bellini and A. Tosi, and the modern Bellini-Tosi aerial system is illustrated in Fig. 130. As originally devised, the aerials were open ones, although it was common practice to have them inclined so that the four upper ends of the aerials should be supported from a single central mast. In 1912, C. E. Prince modified the Bellini-Tosi aerial system by converting the four open aerials to two closed loops, although Bellini (1508) claims to have used closed loops before this date, and the progress in the further development of the system forms the subject of Chapter 5.

Small Rotating Loop Aerials. One of the famous experiments of Hertz was to show that when a loop of wire containing a spark gap was held in certain positions in the neighbourhood of apparatus which was radiating electromagnetic waves, a spark would pass between the spark balls ; if, on the other hand, the orientation of the loop were slightly changed, but the loop kept at the same mean distance from the radiation, the spark would no longer be produced. He ascribed this to a property of the loop as an absorber, a characteristic which had probably been noticed even before this date by Fitzgerald.

H. J. Round gives an account (2001) of experiments which he carried out in New York in 1905 and 1906 which demonstrated the directive properties of frame aerials, and he also obtained a heart-shaped diagram of reception of approximately the form shown in Fig. 54 (*c*) by the combination of frame and open aerials, but largely owing to the insensitiveness of his detector, the work was abandoned.

Later Progress. It was the European war, giving, as it did, such a great stimulus to all branches of wireless progress, which also raised the direction finder from a comparatively undeveloped state and resulted in the production, within a year or so, of a reliable instrument. The valve amplifier was largely responsible for this advance in D.F. work, as the increase in range of the apparatus, which had hitherto only been a few miles, and the increase in signal intensity, brought to light faults which had been overlooked in the earlier designs. With the amplifier there came the " aperiodic aerial " development of the Bellini-Tosi system and also a very great increase in the popularity of the small frame aerial, both of which had been handicapped by the weakness of signals obtained with them by comparison with those from a normal tuned open aerial.

The years immediately following the war were notable for the appearance of the first commercial designs of direction-finding apparatus for ships, and within a few years English. American and German installations were in use by a number of shipping lines.

Since that time there have followed transmitting beacons for marine work, the development of the Adcock aerial for the reduction of polarization errors, the radio compass for use in aircraft, short wave direction finders, ingenious applications of the cathode ray tube, and many other improvements on the original apparatus. Throughout the whole period the investigations of physicists, in many parts of the world, have been steadily adding to our knowledge regarding the propagation of electromagnetic waves and pointing the way to the solutions of many of the problems that have arisen in modern D.F. practice.

CHAPTER 2

PROPAGATION OF ELECTROMAGNETIC WAVES

Mental Picture of Wave Propagation. In order to learn how a simple vertical aerial " receives " and to understand the directive properties of the frame aerial or combinations of frames and open aerials, some sort of mental picture of an ether wave and a knowledge of the basic principles of wave propagation are desirable. It is not proposed, however, to go any more deeply into this latter subject than is necessary to explain the receiving properties of directive aerials, and the apparent effects upon these directive properties that occur when the wave has reached a distant receiving point via the reflecting layers of the upper atmosphere.

The electromagnetic theory and the mathematics involved in the study of the propagation of electromagnetic waves over great distances are matters of the greatest interest and importance in radio communication and also in D.F. but are beyond the sphere of this book.

Electrical Component of Wave. Consider first of all a simple form of transmitting aerial consisting of a vertical wire containing a coupling to a transmitter. In the coil is induced an alternating e.m.f. of radio frequency which results in a current flowing alternately up and down the aerial wire and, since the wire has a certain capacity to earth, it forms a condenser and assumes alternately a positive and negative charge. At the instant when, say, the positive charge has accumulated on the aerial, there will be lines of electric strain between the aerial and earth, which lines, as explained in any book on physics, repel one another in a direction at right angles to their length, but, at the same time, are prevented from expanding indefinitely by their tendency to shorten themselves as much as possible. The whole system is illustrated in Fig. 4 (*a*), in which the lines of electric strain are shown bowed out due to their mutual repulsion. An instant later when the current flows down the aerial again, and the condenser discharges, these lines of electric strain collapse, but due to the energy stored in the aerial coil the current is made to continue to flow

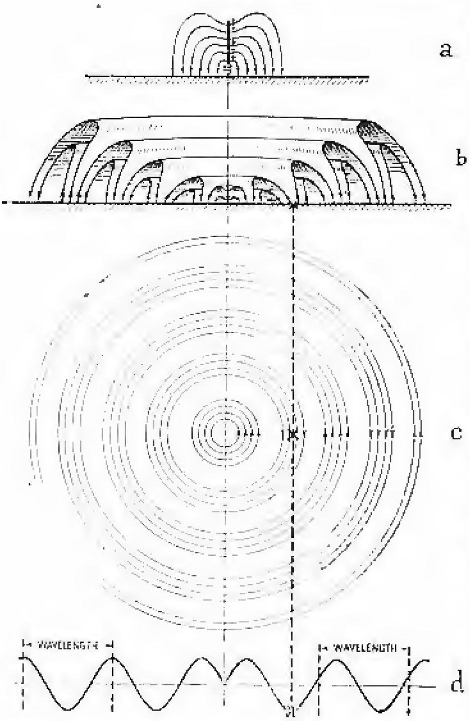

Fig. 4.—Electromagnetic Wave Radiation from a Vertical Aerial.

down the aerial until the latter becomes a negatively charged condenser plate and lines of electric strain are again formed, this time with opposite polarity. Again the lines collapse and the cycle starts once more. Now the ether of space in which these lines of electric strain exist is a medium having properties akin to elasticity and inertia which are the two essentials for the production of wave motion. As a result of this the lines of electric strain which are slipped off the aerial as it is charged and discharged continue to travel out in all directions from the aerial as centre. The speed of this wave motion is the same as the velocity of light, namely, 299,820,000 metres (or roughly 186,000 miles) per second. Since the aerial is being charged alternately positively and negatively, these loops may be marked with arrows as in Fig. 4 (*b*) indicating the alternating electric strain.

Magnetic Component of Wave. Although a static charge of electricity on an aerial—or elsewhere—has only lines of electric strain between the charge and other surfaces of differing electrical potential, this is not so for a moving charge constituting a current or for the wave motion just mentioned. When a conducting wire is made to move, broadside on, across a magnetic field, an e.m.f. will be induced in the conductor and also a current, providing that there is a closed circuit of which the conductor forms a part. If either the direction of motion of the conductor or the polarity of the magnetic flux be reversed, then the direction of the induced e.m.f. and the resulting current will also be reversed or, in other words, the three factors, Magnetic Flux, Direction of Motion, and Induced E.M.F. are mutually at right angles, obey definite laws and cannot be dissociated one from another. Electromagnetic wave motion forms an analogous case, for the direction of motion of the lines of electrical strain is radially from the aerial, the vertical lines of electric strain correspond to the e.m.f.'s induced in the conductor, and there are lines of magnetic force forming concentric circles about the aerial, and which lines are consequently at right angles to both the direction of propagation of the wave motion and also to the lines of electric strain. Fig. 4 (*c*) is a view looking down on 4 (*b*) and only the lines of magnetic flux near the earth are shown, but, of course, they are associated with the electric lines wherever the latter exist. In any normal wave travelling over the surface of the earth the directions of the electric and magnetic components always bear the above relationships to each other. No wireless wave can travel far over a highly conducting surface unless it has its lines of electric force vertical, the reason for which is mentioned later.

In Fig. 4 (*c*) the reversal of the direction of the flux arrows indicates how the intensity of the magnetic force at any given point in space passes through the cycle: Zero, Maximum Positive Force, Zero, Maximum Negative Force, just as is the case with the electric strain, and the two effects are in step or in phase with one another. The energy in the wave is not, as is sometimes stated, concentrated alternately in the magnetic force and the electric force as would be the case if the two effects were in quadrature.

Wave Length. The conventional way of depicting the distribution of electric and magnetic force along the path of an electromagnetic wave at any instant is by means of a curve, as in Fig. 4 (*d*), the ordinates of which above or below the base line represent to scale the intensity of the forces at the place. This base line is a measure of distance and the space between two points where the forces are at a maximum is known as the **wave length** of the electromagnetic wave. It is clearly equally true to define the wave length as being the distance between any two points where the forces are of identical intensity *and are changing in the same manner*.

Frequency. It was mentioned above that the speed of travel of the electromagnetic wave is approximately 3×10^8 m. per second. Suppose now that the frequency of the alternating current in the transmitting aerial be 100,000 per second, then this must also equal the frequency with which successive wave crests pass a fixed point in the path of the wave and, further, this must also equal the total distance travelled by the wave in a second divided by the distance between successive wave crests, or,

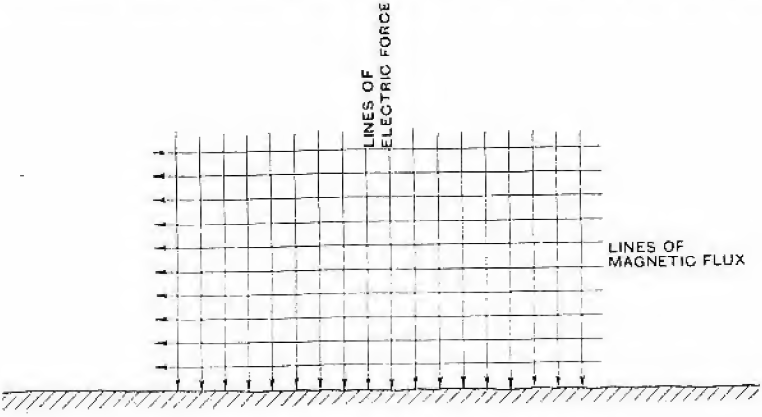

Fig. 5.—Wave Front of Normally Polarized Wave.

$$\text{Frequency } (100{,}000) = \frac{\text{Velocity } (3 \times 10^8)}{\text{Wave length}}$$

$$\text{and the Wave Length} = \frac{300{,}000{,}000}{100{,}000.} = 3{,}000 \text{ metres.}$$

The approximate figure of 300,000,000 metres per second was proposed by the International Technical Consulting Committee on Radio Communication in 1929, in place of the more accurate figure of 299,820,000 on the grounds that, in radio practice, whilst the measurement of frequency is universal and is carried out commercially within an accuracy of 1 part in 100,000, and in laboratories to 1 in 1,000,000, the measurement of wave length is never required more accurately than to 1 part in 1,000.

The easily remembered 3×10^8 introduces an error of 1 part in 1,600 when converting frequency to wavelength but this was considered immaterial and the proposal was ratified at the International Radiotelegraphic Convention of 1932.

Frequency and Wave Length. The modern tendency towards speaking in terms of frequency instead of wave length, more often than used to be the case, dates from the introduction of the " Side Band Theory " and led to a proposal at the above mentioned C.C.I.R. meeting to abandon the use of wave length altogether. Fortunately—for D.F. work at any rate—this somewhat drastic suggestion was not adopted, for, when dealing with the dimensions of di-poles, loop aerials, directional aerial arrays, the distances between spaced aerials, the probable natural periods of steel wire ropes forming the mast rigging of D.F. stations and matters such as these, it will be found just as unintelligible to try and think in cycles per second as it is to attempt to design a band filter in terms of wave length. Both forms of nomenclature are used throughout this book, according to which is the more appropriate—or at other times indiscriminately as in everyday technical conversation.

Wave Front. Within a few wave lengths from a transmitting aerial the lines of both magnetic and electric force are appreciably curved, but at great distances the curvature becomes so slight that the network of horizontal and vertical lines becomes almost a vertical plane presenting, to a receiving aerial, a front that is shown diagrammatically in Fig. 5, and which is called the Wave Front.

We say *almost* vertical because in practice the plane containing the electric and magnetic force in the wave, and which therefore constitutes the wave front, is never truly vertical unless the wave is passing over a surface which has infinite conductivity or is travelling in free space.

The question of the horizontal electric forces in a wave, in the direction of its travel, often leads to some confusion and is worth consideration. To take an extreme case, suppose a wave to be travelling over a perfectly conducting surface and suppose the arrow AB in Fig. 6 to represent the vertical component of electric force and AC to represent in direction and magnitude a horizontal component of electric force. Since AC is a line of electric force, there must be a potential difference between A and C. But we have said that the surface is a perfect conductor and hence—having no resistance—can have no difference of potential and likewise no lines of electric force so that in such a case AC cannot exist.

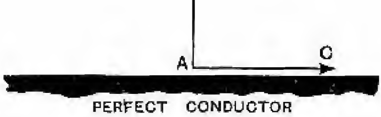

Fig. 6.—Horizontal and Vertical Components of Electric Force.

The sea, with its conductivity of about 10^{-10}c.g.s. units,* may be considered to be of high conductivity in this respect, and Fig. 7 shows a cross-section of a wave front

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* Page 17.

over the sea in which the electric force, being vertical, may be represented in direction and magnitude by the single arrow or vector AB. In the case of a wave transmitted over a part of the earth's surface in which the conductivity is much lower, say for instance 10^{-17} c.g.s. units, there are losses in the semiconducting material which result in a component of electric force in a horizontal plane in the direction of travel of the wave as shown by the two vectors in Fig. 8.

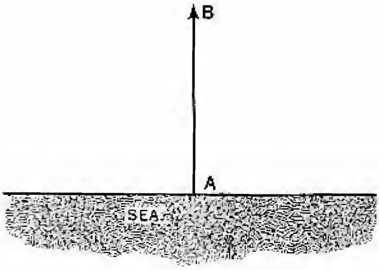

Fig. 7.—Vertical Electric Force in Wave Travelling over High-Conductivity Surface.

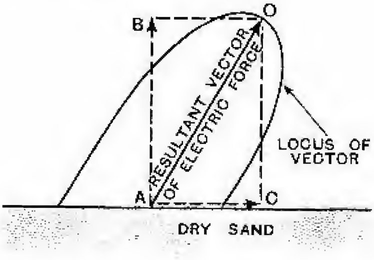

Fig. 8.—Elliptical Electric Force in Wave Travelling over Low-Conductivity Surface.

The problem is rendered more complex because the normal vertical electric force and the horizontal component are not usually in phase with one another so that there is produced a rotating field of elliptical form* as illustrated. The angle of forward tilt increases with frequency and with decreasing conductivity of the surface over which the wave is passing, and has been measured on many occasions. On the dry sandy soil of the Riverhead receiving site of the Radio Corporation of America, Communications, Inc., a tilt of as much as 10° is mentioned by Beverage, Rice and Kellog on very long wave lengths (2309), whilst Smith-Rose and Barfield in experiments carried out for the Radio Research Board in England, found the maximum angle to be less than 1° on wave lengths between 2,600 and 6,900 m., though it was 10° on 450 m.

It may be mentioned that a comparatively thin layer of good conductivity soil below surface layers of low conductivity has been found to have the effect of reducing the forward tilt to zero on wave lengths of the order of 1,250 m. (2711).

For an appreciation of the elementary theory of direction finding it is hardly necessary to take account of this forward horizontal component of the electric field, although a certain type of directional receiving aerial, called the " Wave

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* Page 21.

Antenna" of the R.C.A., which is the subject of the paper mentioned above, depends for its receiving properties entirely upon this component of the wave.

Soil Conductivity. The conductivity of the earth has already been mentioned once or twice and becomes important again later when dealing with the Adcock aerial system in some of its commercial forms. The conductivity is sometimes expressed in electrostatic units and sometimes in electromagnetic or c.g.s. units or alternatively the values of the resistance per centimetre cube may be used. Approximate values, expressed in the last form and with their corresponding values of conductivity, are given below for various types of surface over which transmission and reception may have to be carried out.

SURFACE	RESISTIVITY	CONDUCTIVITY	
	Ohms per cm. cube	Electrostatic Units	Electromagnetic or c.g.s. Units
Sea water	10	9×10^{10}	10^{-10}
Wet earth, or clay	10^2 10^3	9×10^9 9×10^8	10^{-11} 10^{-12}
Normal earth, loam or chalk . .	10^4	9×10^7	10^{-13}
Pure fresh water . .	10^5	9×10^6	10^{-14}
Dry earth . .	10^6 10^7	9×10^5 9×10^4	10^{-15} 10^{-16}
Dry sand	10^8	9×10^3	10^{-17}

The values for conductivity and resistivity vary between rather wide limits for soils of apparently similar types and they also vary with frequency, and for more precise data reference should be made to (3309), (3512) and to tables of physical constants.

POLARIZATION

Plane Polarized Waves. If one end of a rope that is lying straight along the ground, be raised and given a violent up and down movement, a series of waves will travel along the rope, being rapidly attenuated as they reach the part that is in contact with the ground. These are called **vertically polarized waves** because their direction of movement is in a vertical plane through their direction of travel or propagation. The waves of the sea are vertically polarized.

If the movement applied to the end of the rope had been horizontal, the waves would have been in a horizontal plane and would have been called **horizontally polarized.**

Similarly, an oblique transverse movement might have been given to the end of the rope, say in a straight line making an angle of 45° with the vertical, and the waves would then have been obliquely polarized. In all three cases, however, they would be **plane polarized waves,** this name being given to any system of transverse wave motion which takes place in one plane only through the direction of propagation, no matter whether the plane be vertical, horizontal, or in any intermediate direction.

The electromagnetic wave travelling over a good conducting surface is said to be vertically polarized, because its electric force is in the vertical plane through the direction of travel.

Since the associated magnetic force is horizontal, and since it may be desirable to study the receiving properties of aerials from the point of view of magnetic flux linkage, there is a temptation to refer to "horizontally polarized magnetic force," which may be correct, but is confusing. In this book the expression "polarized" will be reserved for application to electric force only, as is customary, although horizontal or vertical magnetic force may be referred to from time to time. Some interesting correspondence on this point occurs in (2629) and (2630).

The Abnormally Polarized Wave. It will be clear from Fig. 4 (*b*) that the wave front must extend to a great distance upwards and if it remains tangential to the direction of travel will be facing upwards and not perpendicular to the ground. In other words, the electric force in the wave, though still in the vertical plane of travel, is tilted backwards and has, in fact, a horizontal component, though not for the reason mentioned on page 16 as the wave is now in free space. The tilt arrives simply from the geometry of the expanding wave shell, and therefore the relatively minute portion of the complete wave front that affects a ground receiving aerial is almost vertical—depending, as has been seen, upon the soil conductivity.

Suppose, however, that the transmitting aerial itself is not vertical but is sloping at some acute angle to the earth's surface, as in the case of the trailing aerial of the aeroplane shown in Fig. 9. The circles of magnetic force surrounding the aerial are now tilted and the lines of electric strain are no longer even approximately perpendicular to the earth's surface when the wave front reaches a ground receiving aerial. Either ahead or astern of the aeroplane, the wave front, on reaching the earth, is tilted, but the lines of electric force remain in the same vertical plane as the direction of propagation of the wave, *and the magnetic lines remain horizontal.* The wave front which is presented to a receiving station which is broadside on to the aeroplane, or which is, in fact, in the position from which the view in Fig. 9 would be obtained, is, however, no longer a normal one. Whilst still at right angles to one another and also at right angles to the direction of travel of the wave between the aeroplane and the ground aerial, *the magnetic and electric lines are now tilted in the plane of the wave front* and the network when it strikes the receiver will be as shown in Fig. 10, instead of as in Fig. 5. Such a wave is still plane polarized but its plane of polarization now makes an angle of some 60° with the vertical plane through the direction of travel and it may be referred to in general as an **abnormally polarized** wave.

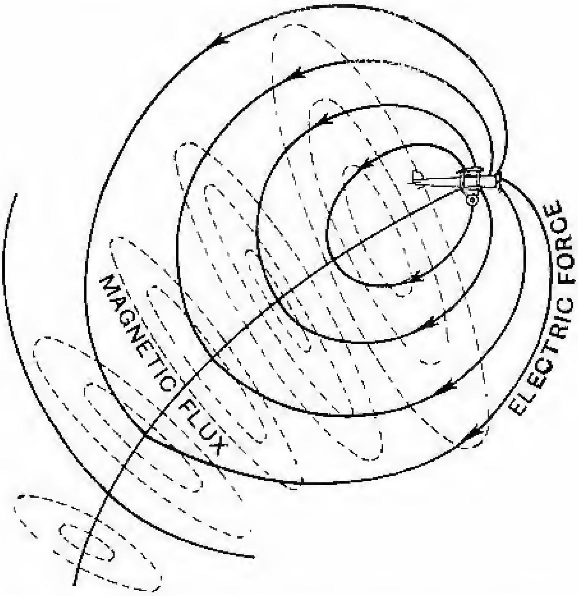

Fig. 9.—Electromagnetic Wave Radiation from Aeroplane Trailing Aerial.

Elliptical and Circular Polarization or Rotating Electromagnetic Fields. Unfortunately, however, the plane polarized wave is not the only type encountered in D.F. reception and to get a picture of the more complex forms it is perhaps helpful to employ vectors. In Fig. 11 (*a*) let the series of vectors from OA to OJ represent the amplitude and direction of the electric force in a vertical plane polarized wave during one half cycle, that is to say from 0° to 180°, during which the amplitude changes from a positive maximum to a negative maximum. In the remaining half cycle it will, of course, continue on until it arrives at its original state and the locus or path of the arrow head of the vector will be simply a vertical straight line as shown on the right-hand side of the diagram.

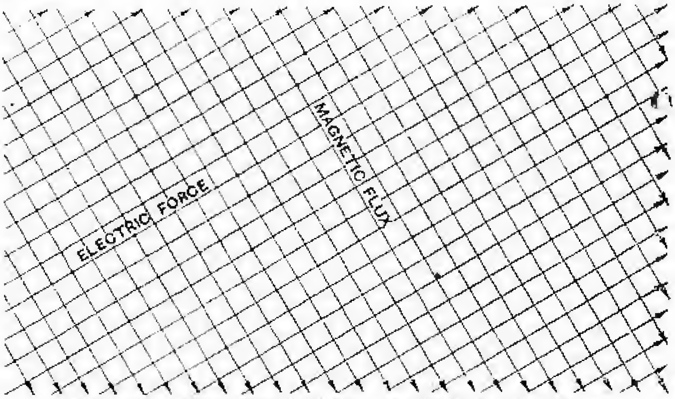

Fig. 10.—Wave Front of Abnormally Polarized Wave.

Fig. 11 (*b*) shows an exactly similar sequence for the horizontally plane polarized wave.

In Fig. 11 (*c*), the wave has components in both planes which are in phase with one another. It may in fact be taken to be the combination of the two waves shown above. These two vectors now add together to make a third vector, the locus of which results again in a straight line, indicating a plane polarized wave but at an angle of 45° to the vertical. Had the amplitudes of the two components—as represented by the lengths of the component vectors—been different, then the resultant angle of polarization would have varied accordingly.

Fig. 11 (*d*) introduces a complication in the form of a phase difference between the vertical and horizontal components which are now seen to be in quadrature, that is to say the vertical component is at its maximum amplitude when the horizontal one is zero and vice versa. The resultant vector now swings through 180° during the first half cycle and the arrow head describes a complete circle during one cycle. This is a **circularly polarized wave** and during one cycle it takes up in turn every plane of polarization, whilst remaining throughout at constant amplitude, although its component in any one plane rises and falls sinusoidally. In fact, a line of electric force in such a wave may be thought of as following a path through space similar to that taken by the blades of an airscrew as it moves forward. This analogy may be pursued a little further, for just as different aeroplane engines may have clockwise or anti-clockwise rotation, so the circularly polarized wave may have **right hand** or **left hand** polarization, a matter that is referred to again later.

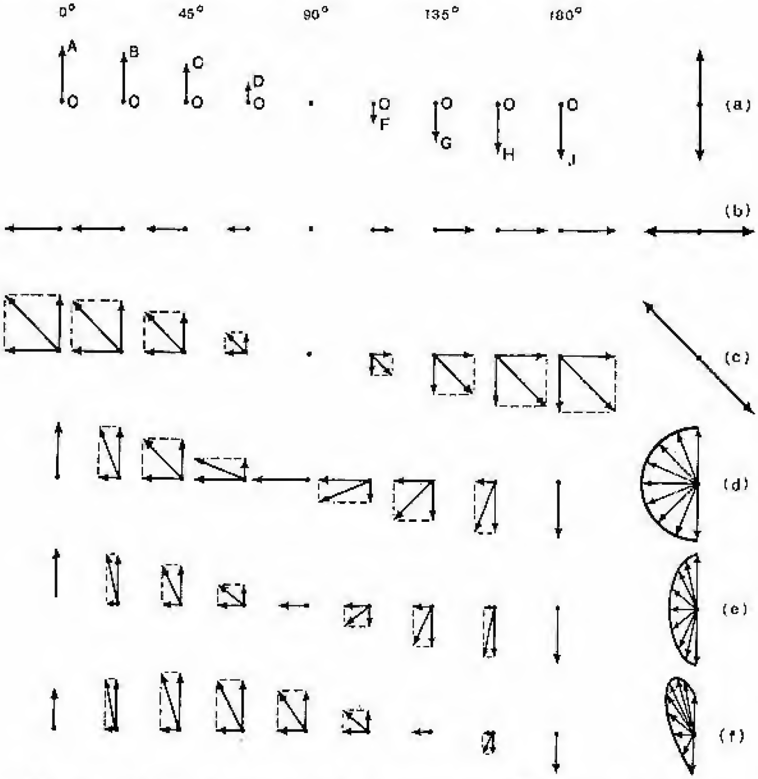

Fig. 11.—Vectors illustrating Plane, Circular and Elliptical Polarization.

Reverting again to the case of the rope, on page 17, a circularly polarized wave in the rope would be produced by a rapid rotatory movement of its free end.

Fig. 11 (*e*) illustrates a state of affairs similar to the circularly polarized wave, but in which the horizontal component wave is of smaller amplitude than the vertical one, with the result that instead of a circularly an **elliptically polarized wave** is produced.

Fig. 11 (*f*) is similar to 11 (*e*) but now the two components are no longer in quadrature, but bear some random phase relation. The maximum of the vertical component is seen to occur after the zero of the horizontal component wave, and the major axis of the ellipse is thus tilted out of the vertical. Compare this with the case of the electric force in a wave travelling over a poorly conducting surface, as in Fig. 8, which is another example of an elliptical vector.

These, then, represent some of the forms of wave motion that arrive at a direction finding aerial system and include types which will be found later to be the cause of some of the most difficult problems in D.F. work.

Ground Waves. Abnormally polarized waves such as those received from aeroplane transmitters and illustrated in Fig. 10 can only exist when they are travelling in free space, and the reason why, as already stated, no electromagnetic wave can travel far over the surface of the earth unless it be normally polarized, may be explained in the following simple manner.

Suppose the line A B in Fig. 12 to represent a line of magnetic force in a wave which has 40° of rotation from normal. The line of magnetic flux now makes an angle of 40° with the surface of the ground and cuts the earth's surface at its lower end. This magnetic flux may be resolved into two components, one of which is normal, i.e. horizontal, and the other vertical. Now, when a conductor is moved between the poles of a magnet or when, say, a piece of copper is held in the field of an alternating current magnet, circulating or "eddy" currents are induced in the copper which dissipate the energy of the magnetic field as heat. In the same way, when the vertical component of the magnetic field of a wave cuts the earth's surface, circulating currents are formed which dissipate this component leaving, after a short distance, only the normal component of the wave.

Similarly, from the electrostatic point of view, any horizontal component of electric force will result in potential gradients along the semi-conducting surface, over which the wave is travelling, and the energy of this component will be dissipated in earth currents.

WAVE PROPAGATION THROUGH THE UPPER ATMOSPHERE

It might seem that since the abnormally polarized components of electromagnetic waves are so rapidly eliminated, the only waves of this nature that could be met with in practice must be those from aircraft transmitters flying over the receiving station, but this is not by any means the case.

Since the early days of long-distance wireless communication, it has been realized that something in the nature of a conducting and reflecting layer must exist in the upper and extremely rarified regions of the atmosphere, which enables electromagnetic waves to travel over far greater distances round the earth's surface than can be accounted for by other means.

Reflection and Refraction. Before beginning the study of the nature and properties of the conducting layer it may be advisable to mention the principles of refraction and reflection, both of which are involved in the action of the layer and also in other aspects of D.F. which are dealt with in later chapters.

The effects of refraction in the case of light waves will be familiar to everyone. If a pencil be held obliquely so that a part of it is beneath the surface of some water, then, from most viewpoints, the pencil will have the appearance of being bent at the point where it enters the water. The effect is due to the fact that light travels more slowly in water than in air, and when the rays of light, reflected from the pencil, leave the water the change in velocity results in a change in the direction of the rays. We may be excused for including at this point an elementary analogy of the process of refraction which explains the effect very clearly.

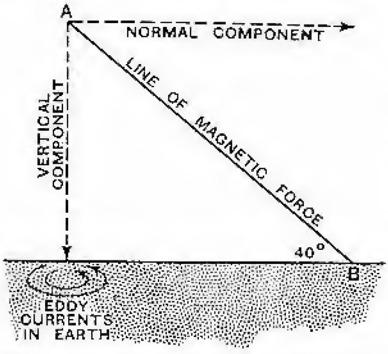

Fig. 12.—Dissipation of Vertical Magnetic Force due to Eddy Currents.

Suppose a number of men to be marching in line, in the direction of the arrow P in Fig. 13, on smooth ground and with a speed of four miles per hour. The line XY represents the boundary between the smooth ground and an area where marching is difficult and over which the speed falls to three miles an hour.

When the line of men reaches the position (*b*), those who have crossed the boundary are seen to be falling behind owing to their reduced speed. At (*c*) the effect is more noticeable still and at (*d*) the whole line are now marching at the reduced speed, and a permanent deviation in the front has taken place, and also a change in the direction of marching if the men march on their new front.

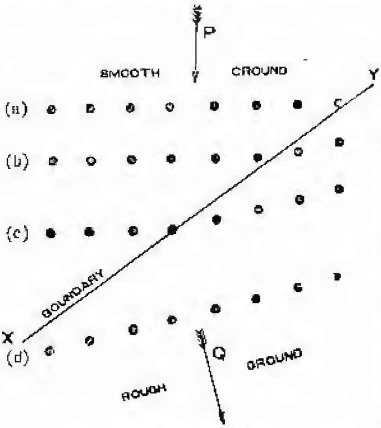

Fig. 13.—Analogy illustrating Refraction.

Such a deflection from the normal direction of travel is almost exactly analogous to refraction, and it is clear that the effect is produced by a change in velocity at the boundary of the two media. Had the men been marching from rough to smooth ground, then conversely they would have swung over to the right instead of the left, whilst, in the case when XY is parallel to the line of men who are marching, no refraction effect is noticed since all the men cross the boundary simultaneously.

So far as the refraction of light is concerned, the whole subject is well known and amenable to mathematical and experimental proof, a very simple relation existing between the angle of deviation of the light ray and the ratio of the two velocities in the different media on either side of the boundary surface.

In Fig. 14, if AB is a ray of light falling on the surface XY of a sheet of glass, the ray on entering the glass will be bent owing to the reduced velocity. AB is called the **incident ray** and B the **point of incidence** whilst BC is the **refracted ray.** PQ is at right angles to the surface, and α and β the **angle of incidence** and **angle of refraction** respectively.

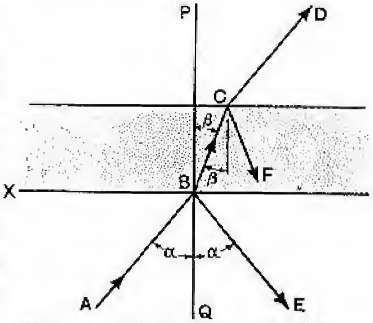

Fig. 14.—Reflection and Refraction of a Light Ray.

For any given pair of media,

the ratio $\frac{\sin \alpha}{\sin \beta}$ is a constant quantity and is called the **refractive index** and is also equal to the ratio $\frac{\text{Velocity of incident ray}}{\text{Velocity of refracted ray}}$.

This constant is usually designated by μ and for Air to Glass is equal to 1·5 whilst for Air to Water it is 1·331. This is more simply written Glass 1·5 and Water 1·331 since, for convenience, the first medium is commonly taken as air and hence μ for air is unity.

Referring now to the point at which the ray leaves the glass and enters the air again, exactly the reverse process takes place. The refractive index now becomes that for glass to air, which is the reciprocal of 1·5 and equals 0·75, and the ray is bent back to its original direction, provided that the two surfaces of the sheet of glass are parallel.

It is important to notice that when the velocity is less in the new medium than in the original one, the ray is bent away from the plane of the boundary surface at the point of entry. It is also to be noted that the change in velocity and hence the change in direction varies with frequency.

In most cases a certain degree of reflection will also take place at the boundary surface, the amount depending upon whether the surface is smooth or ill-defined. In the case illustrated, BE would be referred to as the **reflected ray** and the **angle of reflection** QBE will be equal to the angle of incidence.

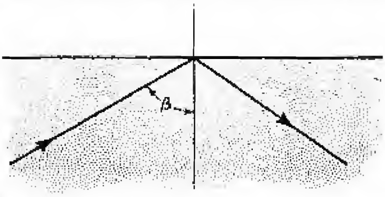

Fig. 15.—Total Internal Reflection of a Light Ray.

Similarly at the point C, there will be reflection along CF and since, on passing from a dense to a less dense medium, the ray is bent nearer to the boundary surface, it follows that for a ray originating in the dense medium, as in Fig. 15, there must be some critical angle, as illustrated, when the ray is unable to escape and the result is **total internal reflection.**

To return to the question of refraction, since wireless radiation also consists of electromagnetic waves, effects similar to those discussed in the case of light are experienced when wireless waves pass across the boundary surface between one medium and another in the course of their propagation. A difference occurs in that it is not customary in this case to specify the refractive index of the media, but to use a term known as the **dielectric constant** designated

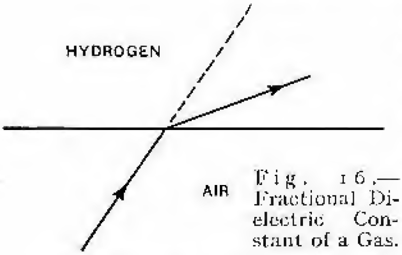

Fig. 16.—Fractional Dielectric Constant of a Gas.

by the letter κ. This constant will be familiar as the ratio between the capacity of a condenser, employing the given material as its dielectric, compared to the capacity of the same condenser with only air between the plates.

In the case of most solid and liquid dielectrics κ is greater than unity, indicating that a wave entering such a medium from air, at an acute angle, will be bent still further into the medium. Some gases, however, have a fractional κ and so the incident ray will be bent back towards the boundary surface as in Fig. 16.

Air has been taken as the reference medium in the case of both μ and κ, but for certain work it is more convenient to refer to a vacuum. In this instance the value of μ is known as the Absolute Refractive Index.

There still remains another phenomenon that is not explained by either simple reflection or refraction alone and that is the bending of a ray out of the new medium and back into the original one again. This is believed to be of common occurrence in the propagation of electromagnetic waves and is referred to again on page 28.

THE IONOSPHERE

Ionization of Gases. When air is in a normal condition it is an almost perfect insulator and has no effect upon the electromagnetic waves that pass through it in their paths over the surface of the earth, in the region known as the **Troposphere,** or region of movement, nor in the higher regions where air movement ceases and which is called the **Stratosphere.** Under certain conditions, however, air, in common with most gases, assumes a semi-conducting state by becoming **ionized ;** that is to say, negative particles of electricity or electrons are isolated from the molecules of gas which are thus left positively charged. This condition may arise in various ways such as by an increase in temperature, by X-rays, by the emanations from radium and similar substances, by cosmic and corpuscular solar radiation and from other causes chief among which is the ultra-violet part of the solar spectrum. During the day-time, from the last mentioned cause, sections of the higher atmosphere become ionized or partially conducting, and hence slightly resistive or opaque to the passage of electromagnetic waves. Benndorf (2628) mentions the conductivity of air at 160 km. high as being some 10^{10} times that at ground level, or equal to the conductivity of dry ground.

The property of gases to diffuse themselves at low pressures leads to a further marked contrast in conditions at a height of say 300 km. above the earth's surface. At atmospheric pressure, for instance, a cubic centimetre of air contains 2.75×10^{19} molecules of gas which, in their constant bombardment of one another, do not move more than 1.2×10^{-5} cm. before coming into collision with another molecule, the average distance travelled being known as the **mean free path.**

At a height of 300 km., the molecular density is of the order of 5×10^{10} per c.c. and a molecule of gas may travel 50 to 80 metres unimpeded.

The Kennelly-Heaviside Layer. Once ionized, these rarified molecules tend to remain in this condition, but lower down, where the pressure is greater, the electrons and positive ions are much more liable to come into contact, and hence to recombine. Furthermore, the radiation that causes the ionization is gradually being dissipated in its passage through the gas, so that eventually a lower limit is reached where no further appreciable ionization takes place. As a section of the earth's surface passes into shadow at sunset, recombination of the ions begins and the lower boundary of the layer rises, although owing to the slow speed of recombination in the higher regions it is probable that a stable condition is rarely reached before the sun rises and ionization begins again.

The first of these layers to be discovered, and the lowest one to have any effect upon electromagnetic waves of the dimensions used for wireless transmissions, has the height of its lower boundary between the extreme limits of probably 80 km. on a summer day (Eckersley 2918) and 126 km. at about 30 or 40 minutes before sunrise (Appleton 3012). This is called the " Kennelly-Heaviside Layer," after the two physicists who independently predicted its existence. It also goes by the name of the **E Layer.**

The Appleton or F Layer. In 1927, Prof. E. V. Appleton found evidence, as a result of observations over a period of some eighteen months, of a second layer above the E layer which was much richer in ionization.

On wave lengths of 400 metres (750 kc.) during the winter of 1926-27 he frequently found that at hours when the E layer might reasonably be expected to be lightly ionized or "thin," waves failed to be reflected by it, but appeared to be coming back from a height of 250 to 350 km. With sunrise the E layer deepened and the 400 metre waves were once more reflected at the normal height of about 100 km.

This layer has received the name of the Appleton or F layer and, although he has suggested (3012) that the evidence of two absolutely distinct layers was not so convincing as to rule out the possibility that the increased time taken by the signals to return to earth may be accounted for by a delay in the E layer, the existence of the second layer has since been fully confirmed.

The F_1 and F_2 Layers. In addition to the E layer and the above so-called F layer, a third is sometimes existent at a height of approximately 200 km., whose characteristics differ appreciably from those of the other two. This third layer is called the F_1, and the Appleton layer is now usually referred to as either the F or alternatively the F_2 when it is desired to distinguish it from the F_1. Further reference is made to this matter on page 36.

Some Physical Constants of the E and F Layers. It has been mentioned that a steady degree of ionization is probably never reached in either layer, and also that the condition is affected by seasonal and other causes, but average day values for some of the parameters may be taken as follows :

	Collision Frequency.	Molecular Density.	Electron Density.
E Layer	10^6 per sec.	10^{13} per c.c.	10^5 per c.c.
F Layer	5×10^3 ,, ,,	5×10^{10} ,, ,,	7×10^5 ,, ,,

Note that collision frequency is proportional to molecular density and is 200 times greater in the E than in the F layer, whilst the electron density is 7 times greater in the F layer, owing to the fact that it is more exposed to ionizing influences than is the E layer.

By night, owing to recombination, the E layer almost disappears and the F layer ionization is much reduced.

BENDING OF THE WAVE FRONT IN THE LAYER AND ITS RETURN TO EARTH

In connection with the mechanism whereby the wave front, after entering the ionized layer, is gradually bent over and finally returned to earth, it is most necessary to visualise some physical explanation. Although the usual mathematical processes lead to accurate results, the intermediate stages of the calculations involve purely abstract conceptions which are of necessity not amenable in most cases to the formation of any mental picture of what takes place.

The Mathematical Argument. In Fig. 17 let M represent an electron, and let the arrow AB be a line of electric force in a wave travelling in the direction shown. The e.m.f. of the wave may be represented by OE in the accompanying vector diagram. Since there is a potential gradient along the line of electric force, and since the operation is taking place in a dielectric (ionized gas), a displacement current will flow just as it would in the dielectric of a condenser, in order to produce the "charge" when a potential is applied to the plates. But this current being capacitative, will lead by 90° on the e.m.f. and is represented by OI_d.

Now the electron M has equivalent mass and, when under the influence of the electric force in the wave, its velocity lags 90° on the applied force or, in other words, it behaves like an inductive circuit. As a result the current that is produced when it moves (current being simply electrons in movement), lags 90° on the e.m.f. in the wave as represented by OI_m. But OI_d and OI_m are in phase opposition so that the resultant displacement current will be given by the difference of these vectors, and will be something less than OI_d.

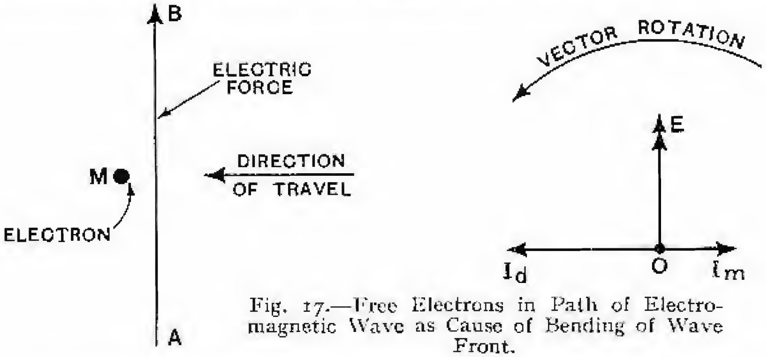

Fig. 17.—Free Electrons in Path of Electromagnetic Wave as Cause of Bending of Wave Front.

The velocity of wave propagation in a medium is given by the expression $\frac{1}{\sqrt{\kappa\,\mu}}$, where μ is the permeability and κ the specific inductive capacity of the medium, and this we know to be the velocity of light when the medium is a vacuum or air free of electrons. But the presence of electrons in the medium has just been seen to have the effect of making the displacement current appear to be less than it should be, which in turn suggests a value for κ which is less than its normal value, and if κ be reduced in the expression :

$$V = \frac{1}{\sqrt{\kappa \mu}}$$

then V must be greater than the velocity of light.

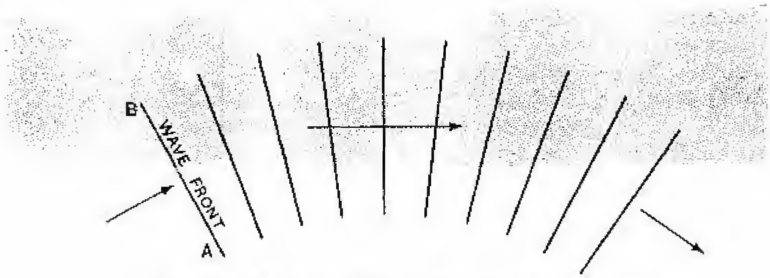

Fig. 18.—Bending of Wave Front in Ionized Layer.

Now consider Fig. 18 in which the wave front is seen to be entering the layer at AB. Since the upper portion of the wave is always deeper into the layer than the lower portion, and since the density of the electrons may be supposed to increase from the lower limit of the layer towards the centre, it follows that the velocity of the upper part of the wave front will always be greater than that of the lower part and the wave will bend over and out of the layer and so travel back to the earth.

This is very briefly the basis of the mathematical argument but is useless as a physical conception because it postulates a velocity greater than that of light, and we know this to be a contradiction of our observations of the physical world.

Huyghens' Construction Applied to Layer Reflection. A rather more satisfying method of considering the mechanism of the returning of a wave from the layer is as shown in Fig. 19, in which Huyghens' construction has been used to illustrate the combined effect of innumerable centres of electron disturbance in the layer, set up by the incident wave.

At the instant when the wave front was in the position AG (assuming the electrical force to be perpendicular to the plane of the paper) the point A would, owing to the movement of the electrons in the field of the wave, become a centre of radiation in all directions as shown by the concentric circles about A.

By the time the main wave front had reached B, and started a similar disturbance there, the radiation from A would have reached H. Similarly by the time C was reached, the radiations from A and B would have reached J and K, so that the line JKC becomes part of the front of the new wave emerging from the layer.

By treating the new wave as produced by the cumulative effect of an infinite number of points of re-radiation in this manner, the effect becomes exactly analogous to reflection and will be referred to as such in later sections of the book.

Elliptical Polarization of Reflected Waves. Owing to the fact that the electrons set in motion by the electric force of the transmitted wave are also vibrating in the earth's magnetic field, their otherwise straightline motion will be converted to an elliptical movement. As a result, the reflected waves will have elliptical polarization, and the rotation may be right hand or left hand depending upon the relation between the direction of travel of the wave and the direction of the earth's magnetic field. (2002), (3509).

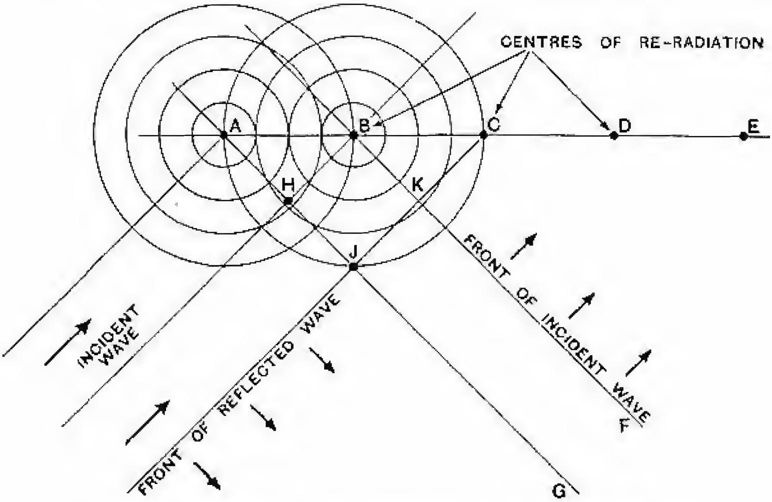

Fig. 19.—Huyghens' Construction Applied to Layer Reflection.

By this process, a wave that leaves an aerial vertically polarized may arrive at the receiving point with a component of horizontal polarization and thus be capable, as will be seen in Chapter 6, of producing errors when using the closed loop D.F.

FREQUENCY OF TRANSMITTED WAVES AND ITS EFFECT UPON LAYER REFLECTION

Long Waves. For very low frequencies of 30 kc. downwards (10,000 m. upwards), the E layer behaves as an almost perfect reflector, and between this layer and the ground the waves are propagated to great distances, at times encircling the earth. With increase of frequency, the penetration into the layer increases, and up as far as what is popularly known as the Medium Wave Broadcasting Band, starting at about 600 kc. (500 m.) there is a very appreciable attenuation in the layer, and waves reach their destination by both direct and indirect paths as shown in Fig. 20. Waves between 500 and 5,000 m. (600 and 60 kc.) are probably reflected back and forth between the layer and the earth several times.

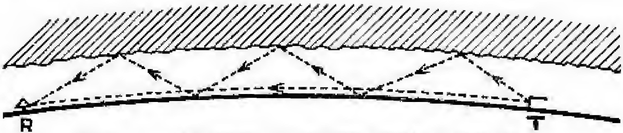

Fig. 20.—Multiple Reflection of Indirect Ray.

Medium Waves. Above 750 kc. (400 m.) there comes a band of frequencies that begin to synchronize with the collision frequency of the electrons and ionized molecules of the E layer, which is of the order of 10^6 collisions per second. This band, the upper limit of which is possibly 1,500 or even 3,000 kc. (200 or 100 m.) can be transmitted over distances of a few hundred miles, but is liable to erratic treatment by the E layer. Reflection at night does extend the range, but fading tends to be violent due to interference between the ground and reflected rays (see page 204).

A certain amount of reflection occurs in the day-time on this band, and is most marked in winter months in high latitudes, under which circumstances ranges are considerably greater.

Short Waves. Above this locally used band of frequencies comes the 3,000 to 30,000 kc. band (100 to 10 m.) corresponding to the so called Short Waves on which the majority of the world's wireless traffic is carried, and on which there is an increasing demand for D.F. facilities. Here there is a notable difference in the action of the E layer, which is normally transparent to frequencies that are well above the collision frequency, and the waves of this band escape through the E layer with some attenuation but without appreciable reflection, only to meet with the latter effect in the F layer provided that the angle of incidence is not too small.

Day and Night Short Waves. The useful range of the short waves is profoundly affected by the degree of ionization of the E and F layers and by their molecular density and, as has already been stated, the former is a function of the degree of daylight or darkness over the route. As a result, the short waves are often grouped under what are popularly known as Day Waves and Night Waves over given routes, and the varying action of the layers by day and night is of considerable interest.

The behaviour of the two bands of wave lengths that constitute the day and night waves differs from year to year for reasons mentioned on page 34, but, for the sake of argument, a period will be considered when the day waves lie between 15 and 25 m. (20,000 and 12,000 kc.) and the night waves between 35 and 60 m. (8,570 and 5,000 kc.). Long distance transmission is assumed, that is to say far beyond the limits of the skip zone (page 40).

The longer wave band, owing to its lower frequencies, produces greater electronic currents in the layers due to the longer time, per cycle of oscillation, during which the electric force is operative. These waves are consequently more readily reflected and have less penetration.

The shorter waves, of frequencies corresponding to 12,000 to 20,000 kc., penetrate much more deeply into the layers before the whole of their energy has been converted into electronic motion, and re-radiated as reflected waves.

For frequencies higher than a figure that varies between 30,000 kc. (10 m.) and about 60,000 kc. (5 m.) the penetration is usually complete for any angle of incidence at the F layer and the **critical frequency** at which this happens, and above which reflections no longer occur, is mentioned again on page 35.

Day-time Propagation. During the day-time, the E layer is well defined since the ionizing influences are intense, whilst recombination is productive of a reasonably even lower surface. The longer "night" waves penetrate the E layer, for the reason just stated, but find in the F layer an electron density seven times as great and are here reflected. Owing, however, to the large number of molecules in the E layer, through which these waves have travelled, there are many collisions and hence considerable attenuation. Although the night waves are reflected to and fro between the ground and the F layer, the attenuation in the E layer is so great that after a few hundred miles the radiated energy is reduced to a negligible amount.

This is illustrated in Fig. 21, where rays from the transmitter are shown with varying vertical angles and with their corresponding reflected rays. It might be thought that the low angle ray such as TDR would have a greater range owing to its fewer transits through the E layer, but it can be shown that due to the more oblique and hence longer path through the E layer, the attenuation is no greater in the end for the many high angle reflections than for the few low angle ones.

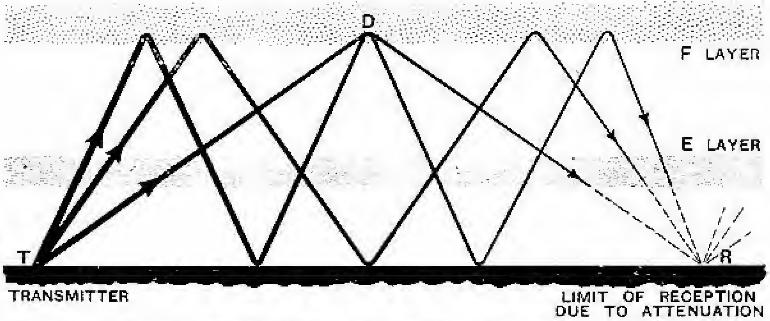

Fig. 21.—" E " Layer Daylight Attenuation of Wave Lengths of 35 m. to 60 m. (approx.).

The shorter band or " day " waves, due to their higher frequencies, and hence more restricted action upon the electrons of the E layer, get through with fewer collisions and proportionately less attenuation. They are reflected from the F layer, after deep penetration, but owing to the smaller molecular density, which is only one two-hundredth that of the E layer, their attenuation is very slight and they are propagated over great distances.

Night-time Propagation. At night the E layer is almost removed by recombination. The F layer remains but with a reduced electron density, as a result of which the short day waves now penetrate too far and are lost completely. The night waves still find enough electron density for their reflection but since the E layer has been almost eliminated, and since the molecular density of the F layer is small, the attenuation of these waves is so greatly reduced that they are propagated between the F layer and the earth over the limits of the globe.

Effect of the 11-Year Solar Cycle. The wave lengths chosen for long distance communication, on the revival of short-wave communication in 1925, were based on world-wide observations of the behaviour of varying wave lengths during day and night conditions at about that time. During the succeeding years, however, a change was noted in that the optimum day results came to be obtained on wave lengths almost as long as the 1925 night waves, whilst the night waves advanced to values of 60 and 70 m. A peak was reached about 1932, since when there has been a steady shortening tendency, and in 1938 night waves of 30 m. are again in use and day waves of 13 m. produce notably better results over routes where 16 m. was the optimum wave in 1935. It is considered that these conditions will continue until about 1940, by which time the lengthening process will again be under way.

The effect is observed mainly in medium and high latitudes, whilst propagation conditions in the equatorial region remain comparatively uniform throughout.

This cycle of change coincides with the 11-year solar cycle, during which the radiations from the sun, that cause the ionization of the E and F layers, pass from a minimum to a maximum and back again. The years of maximum effect are characterized by the appearance of an increasing number of sun spots, during the passage of which across the sun's disc, periods of abnormal ionization are at times produced, some effects of which are illustrated on page 39.

From what has been said regarding the behaviour of the day and night waves, it will be clear that with increase of ionization there will be a tendency for all the effects mentioned to take place on higher frequencies, and hence shorter waves will be more easily reflected, whilst during the sunspot minimum years the reverse is the case.

Critical Frequency for Reflection from the F Layer. It has been mentioned that the F layer exhibits critical frequencies, and these are found to vary with the time of day, season, and also with the above solar cycle.

Rays ascending steeply, and on frequencies higher than the critical frequency will penetrate the F layer, and during the conditions of a late winter night in, say, a latitude of 50°, when both layers are reduced to their minimum electron density, there may be no reflection for any vertical ray having a frequency greater than 2,500 kc. (120 m.). In the day-time, during **sunspot minimum** years of the solar cycle, the critical frequency may be between 5,000 kc. (60 m.) and 6,000 kc. (50 m.), whilst in the **sunspot maximum** years, which are separated by some five or six years from the minimum periods, this critical day-time frequency increases to the order of 7,900 kc. (38 m.) in the summer or 13,000 kc. (23 m.) in the winter in latitudes of about 50°. This latter figure is, however, not the limit, for on days of intense solar activity vertical reflections on frequencies of 15,000 kc. (20 m.) have been observed for short periods of a few hours.

These remarks regarding critical frequency apply chiefly to vertical rays ; for those with flatter trajectories and making a glancing angle with the layer, the chances of reflection are greatly increased.

The F_1 Layer and the Solar Cycle. During the sunspot minimum years, the F_1 layer was present throughout the winter and summer daylight hours in 50° latitudes, whilst during the sunspot maximum years it has been entirely absent except during the months of May, June and July. The F_1 layer is never present during the night, and may be considered to merge into the F_2 to form a single F layer during the dark hours.

GEOMETRY OF THE REFLECTED RAY PATHS

By means of a combination of measurement and calculation that are briefly mentioned in connection with the spaced frame D.F. on page 384, it is possible to find, to within a degree or so, the angle of arrival elevation (ψ in Fig. 22) of any given ray. Knowing the distance between the transmitting and receiving points and the approximate height " h " of the apex of the triangle made by the incident and reflected rays at the layer, simple geometry then gives the number of reflections.

Fig. 21 has shown single, double and treble reflections, or, as they are also known, 1st, 2nd and 3rd order rays. In Fig. 22 a first order ray is shown, a distance of some 3,000 km. separating T and R. The angle ϕ is called the Angle of Incidence at the layer and ψ is the Angle of Elevation at the earth's surface, whilst θ is the angle between the chord TR and the tangent at T or R. The angles ϕ and ψ are thus complementary only when θ equals 0° and therefore only approach this condition at short distances or for high order rays.

Fig. 23 shows graphs for the values of ϕ and ψ for various orders of ray between transmitter and receiver 3,000 km. apart. When the ray is arriving at too flat an angle, the attenuation due to ground losses will be prohibitively large and this imposes a limiting value for ψ which is often taken as being between 3° and 5°. Assuming a limiting value of $3\frac{1}{2}$°, as shown by the dotted line, this precludes the possibility of a single E layer reflection, in the case illustrated, and even a first order F layer ray is somewhat problematical.

Observed angles of elevation fail, at times, to fit in with either the single or multiple reflections between any one layer and the earth, the reason being that owing to changes in conditions over a long route, reflections may occur alternately between the E or the F layers and the earth and there may also be reflections between the layers themselves, before the ray reaches the earth's surface at the receiving station.

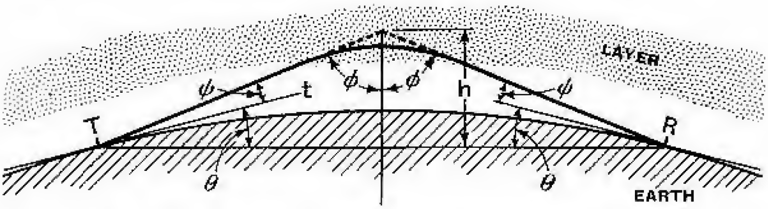

Fig. 22.—Geometry of a "First Order" Reflected Ray.

PULSE TRANSMISSIONS AND THE STUDY OF THE IONOSPHERE

The quantitative study of the ionosphere, and its effect upon wireless propagation, has been immensely aided and, in fact, made possible, by the introduction, by Breit and Tuve (2526), (2527), (2633), of an echo method of observing the height of conducting layers. In the present-day adaptation of the principle, pulses of energy of the frequency to be observed are transmitted by means of a special circuit which ensures that the duration of the pulse shall be of the order of only 1/5,000th of a second, or 0.2 millisecond. If the receiving point be near to the transmitter and the latter be equipped with a vertically directed aerial, the transmitted ray, if on a

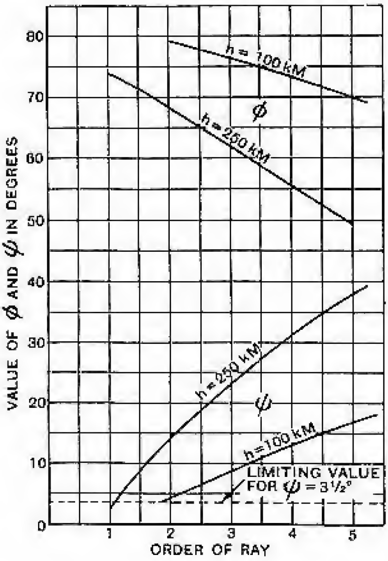

Fig. 23.—Values of the Angles of Layer Incidence φ, and Ground Elevation ψ, for Various Orders of Reflected Ray over a distance of 3,000 km.

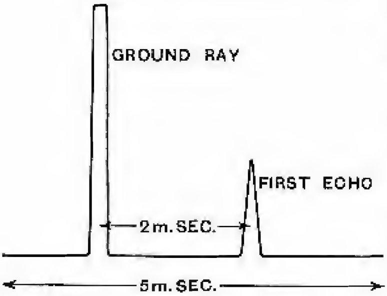

Fig. 24.—Explanation of Oscillograph Record of Reception of Pulse Signal Ground Ray and Echo.

suitable frequency, will be reflected back from one or other of the layers and will arrive at the receiver with a measureable time lag compared to the direct ray signal. The cathode ray oscillograph is used for recording purposes, the time base (page 667) being set to some convenient speed depending upon the intervals at which the pulses are transmitted.

A vertically directed ray, reflected from a height of 300 km., will arrive back at the earth 2 milliseconds after being transmitted, and the image on the screen will appear as in Fig. 24 where the lag of the reflected ray may be easily measured as a proportion of the known length of the time base, which in this case is 5 milliseconds. For transmissions in which the reflections are coming back from great distances, or in the case of the scatter radiation shown in Fig. 32, longer time bases, of say 20 milliseconds, may be used, and the system has many applications.

One such use of the pulse transmission is the study of the effect upon the reflecting layers, of abnormal conditions caused by sun spots, which, with their violent accompanying radiations, are liable to cause such intense increase in E layer ionization, and reduction of ionization of the F layer, that wireless communication on short waves is completely disorganized.

An example of this is to be seen in Fig. 25 which shows the reception of a pulse from a transmitter 15 km. distant using a wave length of 32 m. The length of the time base is 20 milliseconds—less about 1 millisecond for the fly-back. As will be seen there is no reflected ray, the radiation to produce such a reflection at such short range, being, of course, practically vertical, and the normal critical wave length for vertical reflection by day was longer than 32 m. at the time of the observation.

Fig. 26 shows an oscillogram under exactly similar conditions as to wave length, etc., but when a reduced critical wave length made possible the vertical reflection from the F layer, and four perfect reflected rays are seen together with their gradual attenuation.

The distance between the successive echoes is seen to be approximately 0.113 of the total length of the 19 millisecond time base, which thus corresponds to 0.00215 second. During this time a wave would travel 650 km. so that the reflecting point was half this distance or 325 km. above the earth.

Pulse transmissions have at times caused some misgivings as to the symmetry and the ionic composition of the so-called layers, as in several series of such experiments, almost simultaneous vertically reflected rays have been observed to return from distances differing by as much as 40 km., thus tending to indicate anything but well-defined reflecting levels.

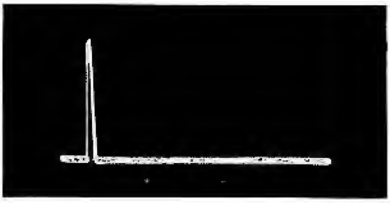

Fig. 25.—
Pulse Reception:
Ground ray only.

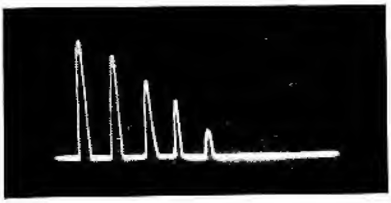

Fig. 26.—
Pulse Reception:
Ground Ray and
Four Echoes.

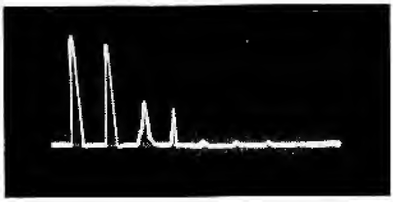

Fig. 27.—Pulse Reception: Ground Ray and Six Echoes.

It should be mentioned that there was considerable " limiting " of the direct ray in the condition illustrated in Fig. 26, it being necessary to reduce the amplifier gain by some 40 d.b. before there was any noticeable reduction in the height of the direct ray image, showing that the latter was probably some 100 times the voltage of even the first reflected ray. In view of the fact that the receiver and transmitter were only 15 km. apart, whilst the first reflected ray had travelled a total distance of 650 km. and had twice traversed the E layer en route, the discrepancy in strength is not unreasonable, but this ratio of field strength varies very greatly with the polar diagram of radiation of the transmitting aerial, as might be expected, and is discussed further in Chapter 10.

Although Fig. 26 shows the images of the reflected rays as evenly attenuated, they are actually varying in relative height continuously, when viewed on the oscillograph screen, and Fig. 27 shows another view during a less symmetrical condition and incidentally illustrates the splitting of the pulse images, and a sixth reflection.

Long Distance Pulse Transmissions. Owing partly to the uneven reflecting surface of the layer, and partly to the geometry of the path which may allow of multiple hops, the energy of a pulse or of any wireless signal is not concentrated in one reflected ray alone, but arrives at a distant point by anything up to 10 or 20 paths, the signals following one another at short intervals. The result of this is that a pulse transmitted from Australia appears when received in England, and viewed on an oscillograph screen, as shown in Fig. 28, namely as a mass of constantly changing signals extending over two or more milliseconds.

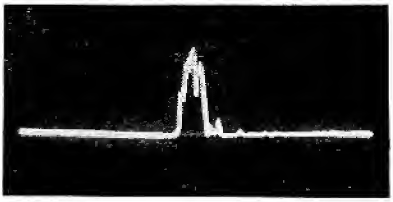

Fig. 28.—Pulse Reception in England from Australia, showing Multiple Ray Signals Superimposed.

The difference in the time of arrival of these multiple rays, their angles of incidence, their types of polarization and other details can all be measured, and are daily adding to the knowledge of the subject of propagation of electric waves and suggesting means whereby the difficult task of direction finding in these complex fields may be carried out.

SKIP DISTANCE

It has been mentioned that the shorter waves are only liable to reflection by the F layer provided that the angle of incidence is not too small, that is to say, the incidence must be a glancing one. If too nearly at right angles to the layer, the ray is likely to penetrate completely, and this effect becomes more marked with higher frequency.

It follows, then, that between the range where the ground ray becomes too attenuated to receive and that at which the first reflected ray from the layer returns to the earth, there is an annular space, with little or no definite signal, and this is called the **skip** or **skipped distance** as shown in Fig. 29.

Places where it is impossible to receive either direct or reflected signals are said to be **"In the Skip,"** whilst those further away are **"Outside the Skip."**

The dimensions of the skip distance depend upon the latitude of the transmitting and receiving points, on the distance between them, on the time of day, the time of year, the height of the layers and their condition, which is in turn dependent upon the 11-year solar cycle. It also varies, of course, with the frequency of the transmission, and on the zenithal polar diagram of the transmitter, but can now be predicted fairly accurately for any given set of conditions.

Skip Curves. The curves of Fig. 30 enable the distance to be found, at which the first reflected wave may be expected to reach the ground for varying latitudes, times of day, season and period of the sun-spot cycle.

The splitting of the two lower curves into winter and summer conditions is due to the fact that the F_2 layer, which controls the skip at these medium distances, is actually denser in both hemispheres during the period of northern winter. For the greater distances, during the period of northern summer, the E layer and sometimes the F_1 layer has the greater influence.

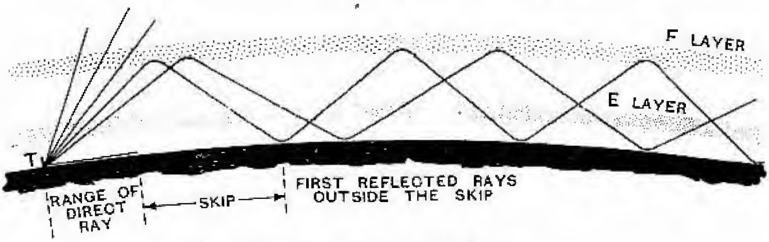

Fig. 29.—The "Skip" Distance.

For distances greater than 5,000 km. the curves remain flat to the limits of the conditions (that is to say, day and night, etc.) under consideration.

As examples of the use of the graphs, the information afforded for a number of sample points, A, B and C may be examined. The point A, for instance, indicates that late on a winter night in the sunspot minimum years and in a latitude above 60°, 110 m. is the shortest wave length for which a reflected wave will reach the ground at a distance of 1,000 km. That is to say, the skip zone will extend from the limits of the ground ray reception to a radius of 1,000 km.

The point B shows that during sunspot maximum years, a 25 m. wave length on a summer day will have a skip zone extending to 500 km., whilst C indicates that a 25 m. wave length during an average day in the sunspot minimum years will have a skip zone extending to about 1,000 km.

The points at which the curves intersect the left-hand ordinate, which is the 100 km. distance line, represent approximately the critical wave lengths for vertical reflection from the F layers and are seen to agree fairly closely with the values given on page 35.

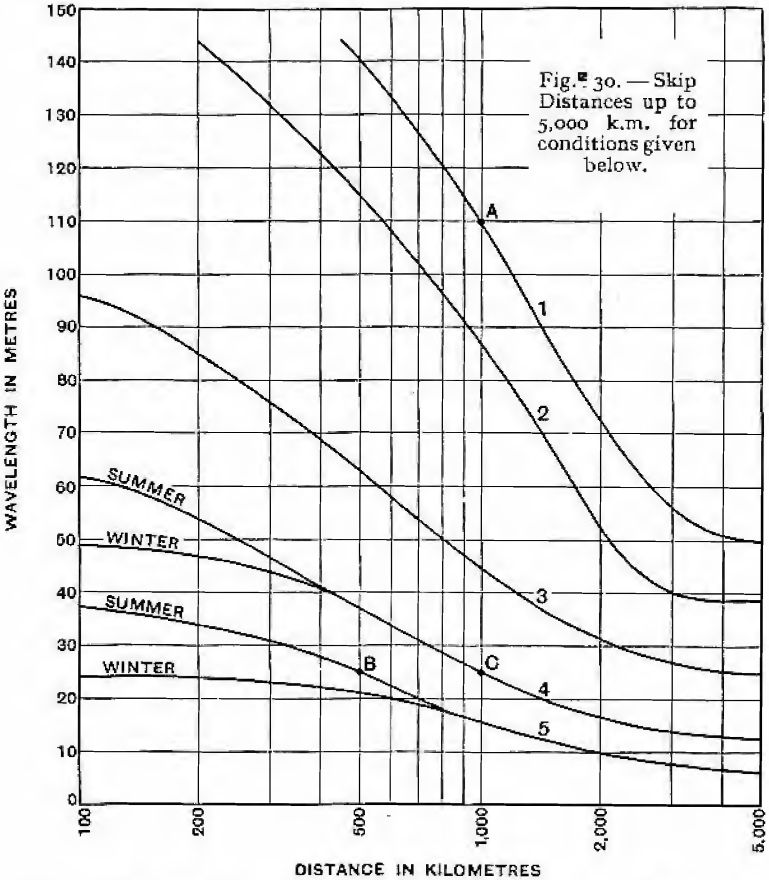

Fig. 30. — Skip Distances up to 5,000 k.m. for conditions given below.

Sunspot Maximum Years.	Sunspot Minimum Years.
1. —	1. Late Night, Winter, above Lat. 60°.
2. Late Night, Winter, Lat. 60°.	2. Late Night, Winter, Lat. 55°.
3. Midnight, Winter, Lat. 40° to 60°.	3. Early Night, Winter, Lat. 30° to 50°.
4. Early Night. (Mean of Summer and Winter curves).	4. Mean Day Value.
5. Mean Day Value.	5. —

SCATTERED SIGNALS

Signals do reach a receiver in the skip area, but they are usually what are called scattered signals which are being reradiated from centres of disturbance in the layers through which the reflected rays are passing. As might be imagined, their strength is uncertain and their apparent bearing, as measured by any sort of direction finding apparatus, bears little relation to the correct direction of the transmitter.

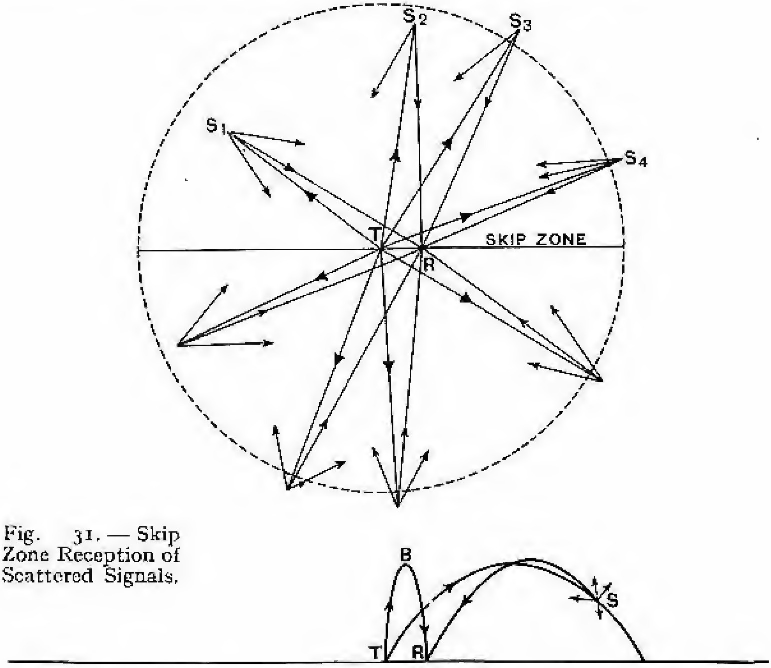

Fig. 31. — Skip Zone Reception of Scattered Signals.

Eckersley's Theory of Scattering. An explanation of the above effect has been put forward by T. L. Eckersley in (2918) and (3503). In Fig. 31, T is a non-directional transmitter and R a D.F. receiver in the skip zone. Under these conditions, the reception at R will normally be extremely poor and bearings will be indeterminate. Owing to the fact that R is assumed to be in the skip, the path TBR is an impossible one except under freak conditions, and it is suggested that signals reaching R arrive from distant points S_1 S_2 S_3, etc., whence they emanate from energized portions of the ionosphere, by a process called " scattering." Clearly, so far as D.F. is concerned, the state of affairs at R is hopeless, the region within the skip distance being—to quote Eckersley—"illuminated by a fog of scattered radiation."

If the receiving point R be sufficiently near to the transmitter to receive a direct ray, then the oscillograph record should show a delay between the times of arrival of the direct ray and the scattered ones, and Eckersley demonstrated this by means of pulses from a transmitter on 30 m. at a distance of 24 km. An oscillogram taken under these or similar conditions is shown in Fig. 32. The time base and periodicity of the pulses were 20 milliseconds and the direct or ground ray is seen to be followed, after a lapse of between 6 and 13 milliseconds, by a band of scattered pulse images which, when viewed on the oscillograph screen, were continuously varying in relative intensity.

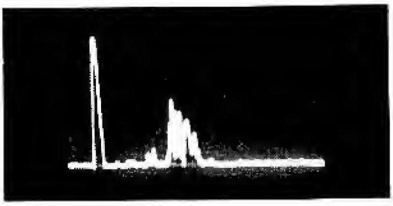

Fig. 32.—
Pulse Reception: Ground Ray and Scatter.

Whilst this scattered radiation often has no definite bearing the direct ray, of course, has a bearing and the separation of the two images for D.F. purposes by the "Pulse D.F." is described on page 223.

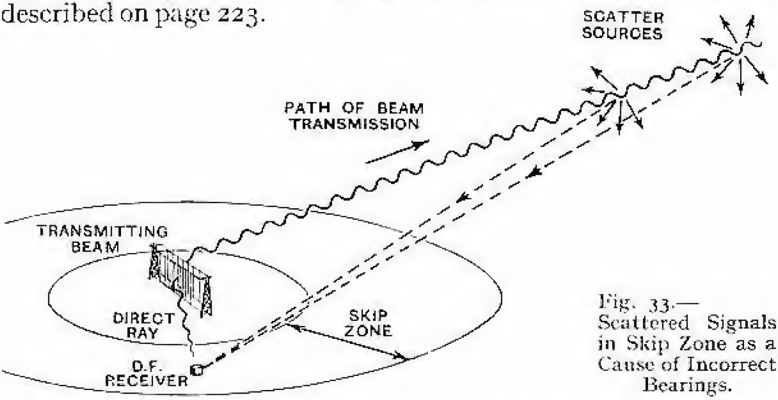

Fig. 33.—
Scattered Signals in Skip Zone as a Cause of Incorrect Bearings.

The time elapsing between the direct and scattered reception indicates total go and return paths of 1,800 to 3,900 km. in length, and it has been conjectured that these represent vertical echo paths of half this distance to some reflecting sources, but there is ample evidence that a horizontal or almost horizontal scatter theory is correct.

A proof of the foregoing appears in the case of a transmitter having a strongly directive aerial, as for instance, the Marconi Beam array. During 1928, Eckersley noticed that a bearing was often obtainable, in the skip zone, of several of these beam transmitters, but that the bearing was always more close to that of the place to which the beam was directed than it was to the transmitter itself. This he explained by the suggestion that, whilst the ground ray strength from the transmitter was negligible, there were rays of scattered radiation from the ionosphere which, owing to the fact that the transmitter was a beam, were all arriving from points along the beam path and hence approximately in the direction of the *receiver*, and not the transmitter, as suggested in Fig. 33.

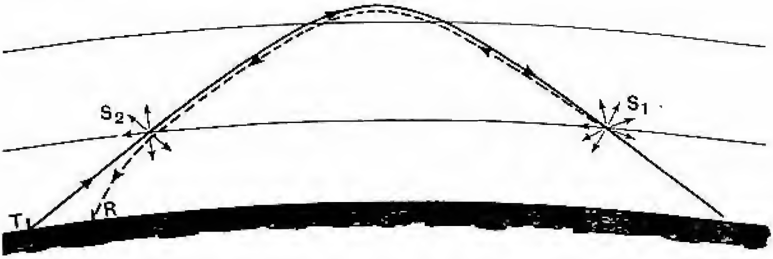

Fig. 34.—Near and Distant Scatter Sources.

This possibility of incorrect bearings being obtained due to scattered radiation becomes very important in short wave D.F. work and is mentioned again on page 377.

More recent work by Eckersley confirms that in addition to the long-distance scatter centres, as shown in Fig. 34 at S_1, there is also a nearer source at S_2, both occurring in the E region. With the receiving point a few kilometres from the transmitter T, the delay in the arrival of the near scatter has been observed and the angle of elevation measured. From the known geometry of the ray paths this gives values for the height of the source of this scattered radiation as 90 to 200 km.

Range and Wave Length Limits of Scattering. Owing to the distance to be covered by the scattered radiation, in its paths from the transmitter to the distant point in the ionosphere and back to the receiving point, the power required to produce a distinguishable signal is of the order of $\frac{1}{4}$ to $\frac{1}{2}$ kW. As a result of this, scattering has been unobserved by a number of other workers using pulse transmissions, the power not having been great enough for the scattering to be distinguished above noise level in the receiver.

Scattering decreases with increase of frequency above 7 Mc. and is usually absent below 2,500 kc. (120 m.).

Multiple Rays and Direction Finding. The presence of E and F layer reflections, and possibly scattering, as well as the ground ray result in a complex signal only the last-mentioned component of which can be relied upon to provide an accurate bearing with a simple loop D.F.—and then only under most favourable conditions. Modern developments have, however, been productive of apparatus capable of a good performance under very adverse conditions, but the subject must be postponed until Chapter 10, dealing with direction finding on short waves.

ULTRA SHORT WAVES.

The waves from 10 m. down to about 3 m. (30,000 to 100,000 kc.) show signs of becoming increasingly important for navigation purposes. These waves have a number of points in their favour, and the difficulties in their application are being rapidly overcome as our knowledge of the technique of the transmission and propagation of these waves increases.

One striking feature is that, in general, they are not reflected by either the E or the F layers, so that any ray directed upwards from the earth is lost and useful transmission is limited to the direct ray.

It was at one time considered that the geometry of light propagation could be applied to the ultra-short-wave band and that the direct ray range was limited to the optical range from the transmitter. This has been shown to be incorrect, both by mathematical reasoning and also by the fact that signals on wave lengths of 7 m. or even less are received over distances of thousands of miles. These extreme ranges are exceptional, however, and are due to reflections from layers that are greatly influenced by sun-spot periods.

Reliable ultra-short-wave ranges are nevertheless appreciably greater than the optical range, but are a function of the height above the earth's surface of the transmitter and receiver and can now be calculated with a fair degree of accuracy (3610).

OPTIMUM WAVE LENGTH FOR LONG-RANGE D.F.

In subsequent chapters (6 and 10) the difficulties are discussed of direction finding at night-time on long waves, and at any time on short waves, over medium distances owing to the polarization errors to which the elementary form of D.F. is susceptible. It is here assumed, however, that one of the systems is in use that is not subject to the above errors, and that it only becomes necessary to choose wave lengths that will give the optimum signal strength at the desired ranges.

Long-range D.F. is used almost exclusively for aircraft and for the first 400 km. or so of any route, the communication would be carried out on the normal aircraft wave, which is 900 m. in England. This wave might be relied upon for much greater distances under good conditions but, in the tropics, atmospherics would limit its use and a shorter wave would probably be used. The American aircraft wave is 180 m.

Beyond 400 km. the angle made with the ground by the reflected short-wave rays begins to be less steep and conditions become more favourable for taking bearings on them. The rest of the route would therefore be covered by wave lengths that will be found to vary over almost the whole of the short-wave band.

Eckersley-Tremellen Shadow Charts. The selection of the optimum wave for communication between any two points of the surface of the earth has been rendered comparatively easy by the construction of a series of charts by T. L. Eckersley and K. Tremellen (Marconi) which show the varying ionospheric conditions over the whole globe for varying seasons, periods of the solar cycle and the degree of light and darkness over the route. By reference to other data based partly on calculation and partly on long experience of communication problems, the required wave length can then be found.

These charts cannot usefully be reproduced in miniature, but K. Tremellen has prepared a series of sets of curves, adapted from the above charts, which enable optimum daylight waves for ranges up to 10,000 km. to be found, and minimum safe night waves up to ranges of about 3,000 km., and these are reproduced overleaf.* Beyond 3,000 km. the choice of night waves becomes too complex to be found by simplified methods, but such ranges would be exceptional in D.F. work. It is also assumed that the minimum range is 400 km. so that the direct ray need not be considered.

Graphical Method for Selection of Wavelength

Daylight. During daylight over the whole route, the selection of the wave is simple and is shown by Fig. 35, where

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* By kind permission of K. Tremellen and Marconi's Wireless Telegraph Co. Ltd.

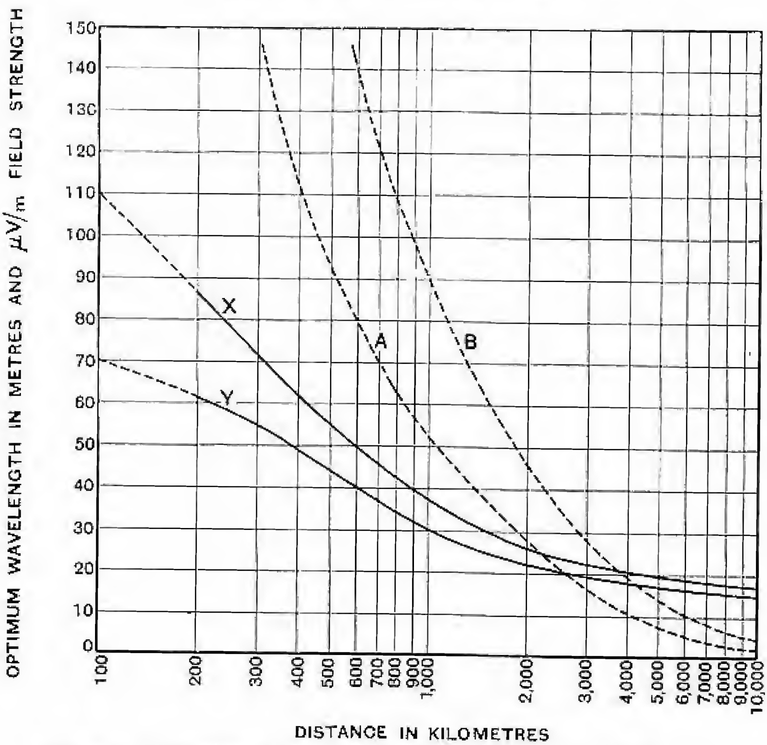

Fig. 35.—Optimum Wave Length Curves XY for Daylight Conditions, with Probable Field Strength Values AB.

the choice for any given range in kilometres lies between the limits of the curves X and Y. This should enable a wave to be chosen that lies in an aircraft band. If the shorter limit be exceeded there is a probability of being in the skip, whilst too long a wave will result in attenuation and loss of signal strength.

The curves apply mainly to temperate latitudes during the sunspot minimum years, and the wave length values will be rather shorter in the sunspot maximum years for these latitudes and shorter at all times for tropical latitudes.

Curves A and B give probable field strengths in microvolts per metre for 1 kW. radiated. The A curve refers to hours round about mid-day in the tropics, or in the summer in temperate places, whilst B refers to early morning and late afternoon for the temperate latitudes and also for the whole day in the winter under these conditions. In using the curve it should be remembered that the field strength in microvolts per metre (see page 55) is proportional to the square root of the power radiated, so that for $\frac{1}{100}$ kW. radiated, the field strengths will be $\frac{1}{10}$ of the values shown. In this connection

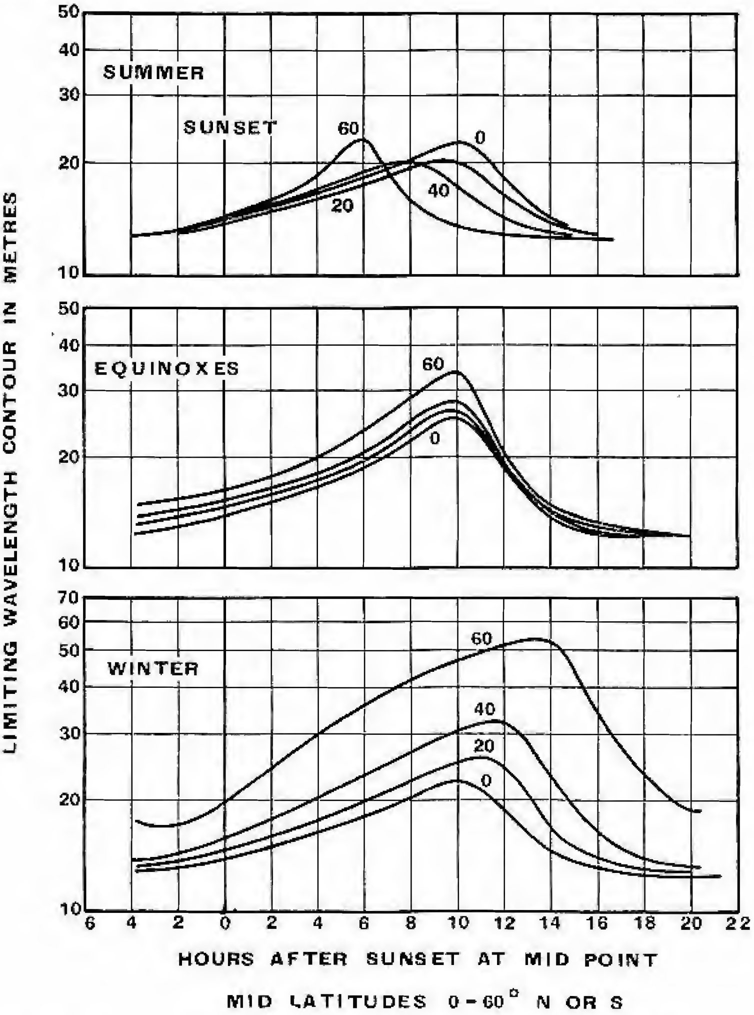

Fig. 36.—Wave Length "Contour Figure" Curves for Ascertaining Minimum Safe Wave Length during Darkness over Route.

it may be mentioned that the power radiated by aircraft transmitters varies from 10 to 40 watts. Sixteen watts is a common figure, and, this being about $\frac{1}{64}$ of a kilowatt, the readings on the curve will have to be divided by 8.

Night Conditions. During darkness over the route, or when there is a combination of darkness, twilight and daylight, the choice of wave becomes more complex since the height and constitution of the reflecting layers continue to change throughout the dark hours, the period of maximum "ionospheric darkness" occurring just before dawn.

A factor called "wave length contour figure" is first obtained from one of the three families of curves of Fig. 36, these having reference to latitudes from 0° to 60° for Summer, Winter and the Equinoxes. The base-line gives the local time of sunset at the midpoint of the route, and the wave contour figure is read off on the vertical scale and is then applied to the curves

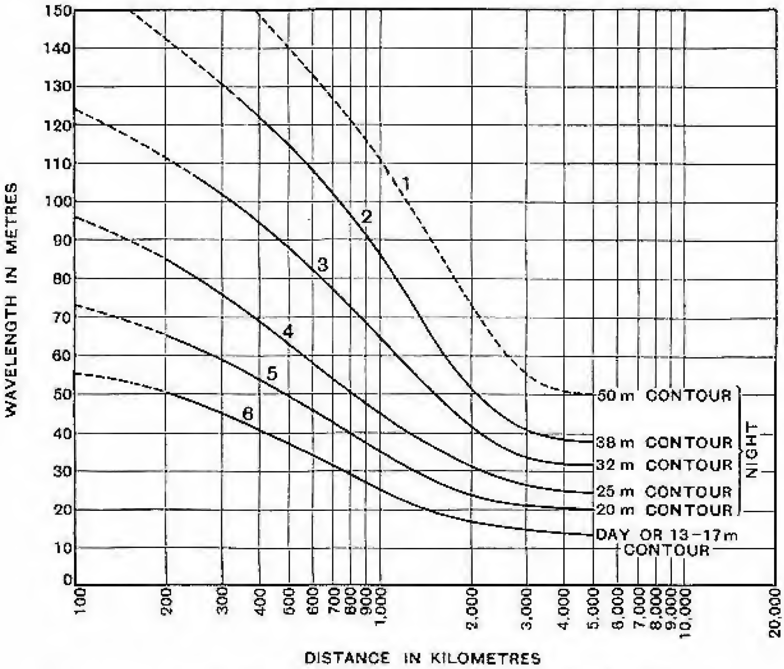

Fig. 37.—Minimum Safe Wave Length Curves for Darkness over Route.

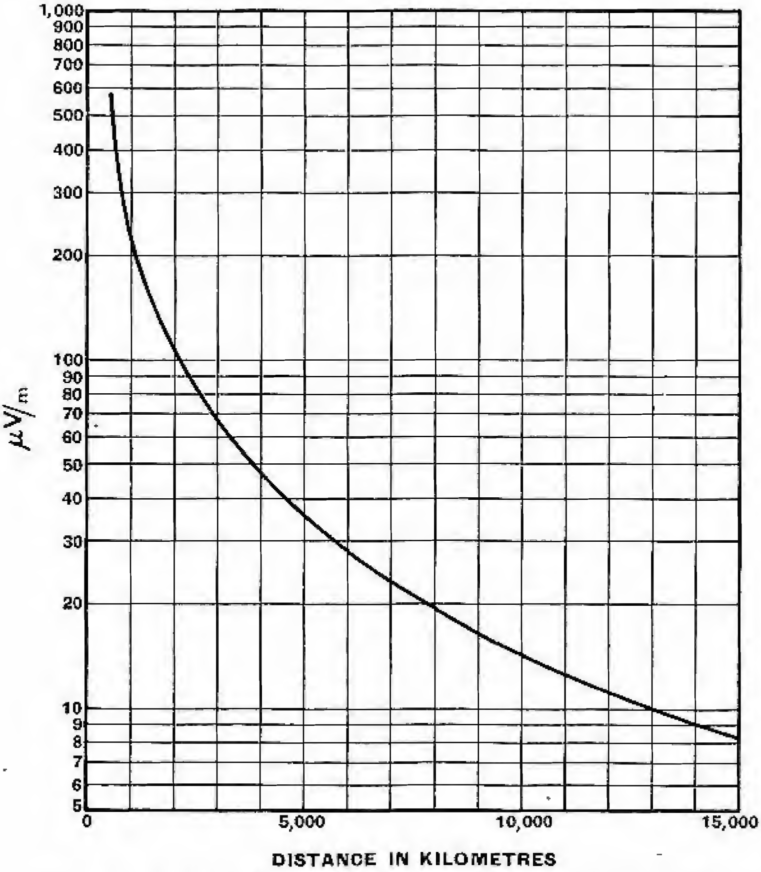

Fig. 38.—Probable Field Strength for 1 kW. Radiated during Darkness over Route using minimum safe wave length.

of Fig. 37. These latter graphs correspond to various values of wave contour and indicate, on the vertical scale, the minimum safe wave length for the required range in kilometres.

Wave lengths shorter than those indicated will be in the skip, whilst longer waves will be subject to increasing interference from atmospherics.

Fig. 38 again shows the approximate field strengths for various ranges at night with 1 kW. radiated. The fields are taken as being independent of wave length and the remarks regarding the daylight curve of Fig. 35 again apply.

Local Sunset Times. The time of local sunset at the mid-point of the route affects the choice of wave length from the contour curves in Fig. 36, and this can be found from the table below. It is necessary to avoid carefully any confusion of the seasons when using the sunset table, or the curves of Fig. 36, and to remember, for instance, that the summer curves must be used for January in the Southern Hemisphere.

LOCAL TIME OF SUNSET
(TO NEAREST 15 MINUTES)

Northern Hemisphere	Lat. 0	Lat. 10	Lat. 20	Lat. 30	Lat. 40	Lat. 50	Lat. 60	Southern Hemisphere
Jan. 1–Dec. 12	1800	1745	1730	1700	1630	1600	1445	June 10–July 3
Jan. 21–Nov. 22	1800	1745	1730	1715	1645	1615	1515	May 21–July 24
Feb. 8–Nov. 3	1800	1745	1730	1715	1700	1645	1600	May 1–Aug. 12
Feb. 17–Oct. 26	1800	1745	1745	1730	1715	1700	1630	Apr. 22–Aug. 22
Feb. 28–Oct. 14	1800	1800	1745	1745	1730	1730	1700	Apr. 11–Sept. 2
Mar. 13–Oct. 1	1800	1800	1800	1800	1745	1745	1730	Apr. 1–Sept. 15
Mar. 21–Sept. 24	1800	1800	1800	1800	1800	1800	1800	Mar. 21–Sept. 24
Apr. 1–Sept. 15	1800	1800	1800	1800	1815	1815	1830	Mar. 13–Oct. 1
Apr. 11–Sept. 2	1800	1800	1815	1815	1830	1845	1900	Feb. 28–Oct. 14
Apr. 22–Aug. 22	1800	1800	1815	1830	1845	1900	1930	Feb. 17–Oct. 26
May 1–Aug. 12	1800	1815	1830	1845	1900	1915	2000	Feb. 8–Nov. 3
May 21–July 24	1800	1815	1830	1845	1915	1945	2045	Jan. 21–Nov. 22
June 10–July 3	1800	1815	1830	1900	1930	2000	2115	Jan. 1–Dec. 12

Example of the Use of Wave Length Curves. In Figs. 39 and 40 has been plotted an imaginary air route between Portsmouth and St. John's, Newfoundland, the flight being supposed to start from Portsmouth at 16.00 G.M.T. The problem is to find the optimum wave for communication with the aircraft, and for D.F., from the terminal airports during each hour of the flight. The two diagrams show these results plotted for winter and summer conditions and the method of using the curves for the purpose is described below.

The length of the great circle route is 3,800 km., and, assuming a ground speed of 200 km. per hour, the time taken will be 19 hours and the position of the aircraft at each hour is shown. Consider now the conditions over the English end of the route at, say, 02.00 G.M.T. during mid-summer.

At 02.00, the aircraft will have travelled 2,000 km. and the mid-point of the route will be at 1,000 km., which is in approximately Lat. 53° N. and Long. 16° west of Greenwich. In this latitude, the local time of sunset during the latter part of June (from the table) is about 20.30 local time. As the point is 16° west of Greenwich, local time will be just over 1 hour slow on G.M.T. so that the G.M.T. of sunset will be, say 21.30 (see page 711). The time selected, namely 02.00 G.M.T. is therefore 4½ hours after sunset at the mid point of the route.

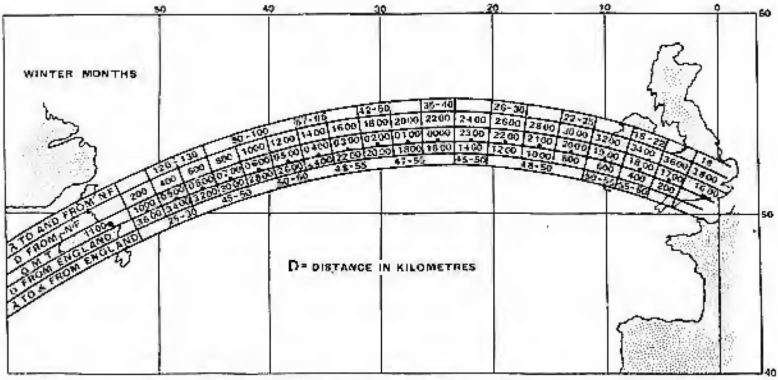

Fig. 39.—Optimum Wave Length for Aircraft/Shore D.F. Communication, Sunspot Minimum, Winter.

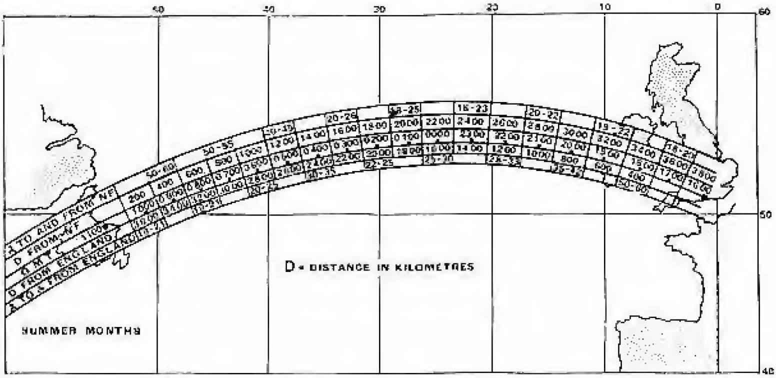

Fig. 40.—As Fig. 39, but Sunspot Minimum Summer.

From the summer group of curves in Fig. 36, it is seen that for Lat. 53° and $4\frac{1}{2}$ hours after sunset, the wave length contour would be approximately 19 m. Transferring this to Fig. 37, it is seen that the nearest contour line, namely the one for 20 m., gives, for a distance of 2,000 km., an optimum wave length of about 23 m. A value of 22 to 25 m. is marked on the chart.

Since the wave lengths given by the curves are "minimum safe" values, they have been increased in some cases in Figs. 39 and 40. Whilst making the reception somewhat more liable to interference from atmospherics, this increase allows a further safety margin to cover the variations in critical frequency that are known to take place from day to day.

Use of Curves in Sunspot Maximum Years. As stated previously, the data given refers to the conditions existing during sunspot minimum years. For the sunspot maximum years, shorter wave lengths than those calculated from the curves can be used both by day and night without risk of encountering skip effects, and the new values can be obtained by reducing the minimum wave as obtained from Fig. 36 and 37 by 20%.

Thus the minimum wave length for the above example will be 18 to 19 m. for the sunspot maximum years, in place of 23 m. For years intermediate between sunspot maximum and minimum years, the value will probably be intermediate between these figures.

CHAPTER 3

DIRECTIVE PROPERTIES OF AERIALS

Magnetic Flux and Open Aerial Reception. When a conductor is cut by lines of magnetic force, an e.m.f. is induced in it; this is one of the elementary principles of electromagnetism. The intensity of the electro-motive force generated in the wire is proportional to the *rate* at which the lines of force cut it. If 100,000,000 lines per second cut the conductor, the e.m.f. produced is 1 volt, and consequently if 1,000,000,000 lines cut it per second, the e.m.f. produced is 10 volts, and so on.

Potential Gradient. Since the magnetic flux and lines of electric force are inseparably associated in the electromagnetic wave, the induced e.m.f. may equally well be considered from the electrostatic viewpoint, and we must then concern ourselves with potential differences along vertical lines of electric force. This is usually measured in millionths of a volt per metre length, measured vertically; being written µv/m, that is to say microvolts per metre, and commonly referred to as the potential gradient of the field.

In such a case, the voltage induced in an aerial is given by the product:

$$\left(\begin{array}{c}\text{Micro-Volts}\\ \text{per metre.}\end{array}\right)\times\left(\begin{array}{c}\text{Effective Height*}\\ \text{of the aerial in}\\ \text{metres.}\end{array}\right)=\left(\begin{array}{c}\text{Micro-Volts}\\ \text{induced in}\\ \text{aerial.}\end{array}\right)$$

As an example, an aerial of 5 m. effective height, in a field of 200µv/m would have an e.m.f. of 1,000µv or 1 millivolt induced in it.

Phase of Open Aerial E.M.F. In considering the manner in which an aerial receives it may be found simpler to think only of the magnetic force in the wave. Since the magnetic force in a normally polarized wave is horizontal, it follows that any conductor placed vertically in the path of the wave will be cut by these lines of magnetic force, and the state of affairs in the case of a receiving station is shown in Fig. 41. Here the aerial wire is represented by AB, the incident wave being indicated by the sine curve, the ordinates of which are a measure of the instantaneous intensity of the magnetic flux in the wave at various positions in its path. In Fig. 41 (*a*) we have a picture of the relative positions when the sine curve is crossing the zero axis at the receiving aerial and when there is consequently no magnetic flux cutting the wire and no induced e.m.f. An instant later, in Fig. 41 (*b*), the wave has moved forward a quarter of a wave length and the intensity of the field cutting the aerial is represented by OX. This field is at its maximum in the negative direction and therefore the maximum negative e.m.f. is being generated in the wire. A quarter of a period later, the flux is again zero in the neighbourhood of the aerial accompanied by zero induced e.m.f. as shown in Fig. 41 (*c*). The flux now reverses in direction, and begins to grow to its peak value in the positive sense, the e.m.f. in the wire following it exactly until in Fig. 41 (*d*) it has again reached a maximum but in the opposite direction to that shown in Fig. 41 (*b*).

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*See page 57.

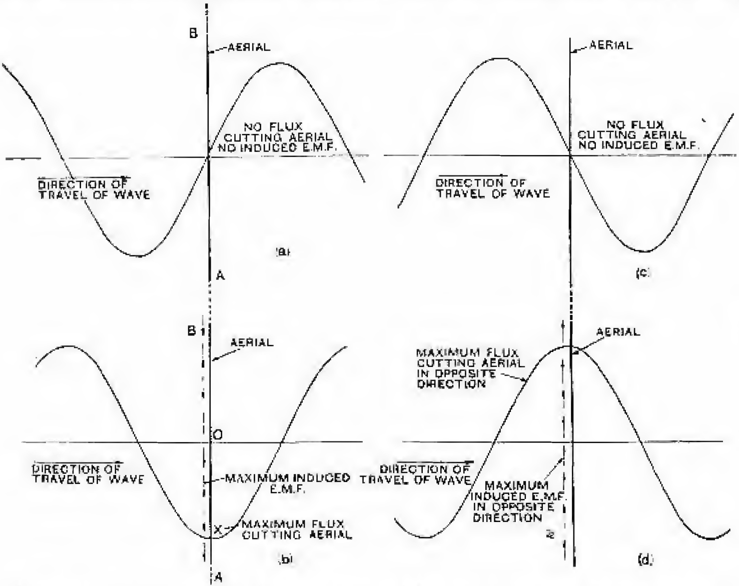

B
AERIAL
NO FLUX CUTTING AERIAL NO INDUCED E.M.F.
DIRECTION OF TRAVEL OF WAVE
(a)
A
AERIAL
NO FLUX CUTTING AERIAL NO INDUCED E.M.F.
DIRECTION OF TRAVEL OF WAVE
(c)
B
AERIAL
O
DIRECTION OF TRAVEL OF WAVE
MAXIMUM INDUCED E.M.F.
X
MAXIMUM FLUX CUTTING AERIAL
(b)
A
AERIAL
MAXIMUM FLUX CUTTING AERIAL IN OPPOSITE DIRECTION
DIRECTION OF TRAVEL OF WAVE
MAXIMUM INDUCED E.M.F. IN OPPOSITE DIRECTION
(d)

Fig. 41.—Induction of Alternating E.M.F. in an Open Aerial by an Electromagnetic Wave.

From these considerations it is clear that the e.m.f. induced in the wire is sinusoidal because the intensity of the flux is represented by a sine curve. We also see that an alternating e.m.f. is induced, in an aerial wire, of the same frequency as that of the wave, and it is important to notice that the induced e.m.f. is *in step* or *in phase* with the flux in the wave, being a maximum when the flux is a maximum and zero when the flux is zero.

Effective Height of an Aerial. Since the e.m.f. induced in a conductor is proportional to the rate at which lines of magnetic force are cutting it, and since the magnetic field in a normal wave is horizontal, the induced e.m.f. in an aerial is proportional to the height. It should be borne in mind, however, that this is not strictly true, since in the case of a vertical open wire, although a uniform field induces the same e.m.f. per unit length of the wire at the top and bottom of the aerial, the current is a maximum at the bottom and zero at the top. The result is that more work is done by a given potential difference per unit length of wire in the lower sections of the aerial than is done near the top—work being the product of current and potential drop.

It follows from this that a flat-topped aerial, having most of its capacity concentrated in the horizontal limb, will have current flowing at the top as well as the bottom of the vertical portion of the aerial, and more work will be done by a given strength of magnetic field than in the case of a simple vertical wire of the same geometric height.

Every aerial has, therefore, what is called an " Effective Height " which is the height which must be reckoned for the purpose of ascertaining received e.m.f. or radiation resistance. The effective height of a flat-topped aerial is very nearly equal to its geometric height, but that of a vertical wire is only $\frac{2}{\pi} = 0{\cdot}635$ of this figure.

Aerial Tuning. In the case of an ordinary low frequency alternating current circuit, the current is given by the expression :

$$I = \frac{E}{\sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n C}\right)^2}}$$

Where : I=Current.
E Induced E.M.F.
R Resistance.
n Frequency.
L Inductance.
C Capacity,

and the denominator of the fraction is known as the impedence. The total reactance of the circuit is dependent upon the relation between the inductive reactance $2\pi n L$ and the capacity reactance $\frac{1}{2\,\pi\,n\,C}$ and is zero when these two are equal. When this latter condition exists, the maximum altrenating current will flow in the circuit for a given applied alternating e.m.f. and is equal to

$$\frac{E}{\sqrt{R^2 + 0}} = \frac{E}{R}$$

If now L or C be increased—which we know to correspond to an increase in the wave length or a decrease in the natural periodicity of the circuit—then $2\,\pi\,n\,L$ will be greater than $\frac{1}{2\,\pi\,n\,C}$ and the circuit will have **inductive reactance and lagging current.** Conversely if L or C be reduced, we get reduced circuit wave length and increased circuit frequency together with **capacitative reactance and leading current.**

Now a vertical wire, grounded at its lower end, can be considered as an ordinary alternating current circuit containing Inductance, Capacity and Resistance. The inductance is that of the wire itself, the condenser is formed by the capacity of the wire to earth and the wire must always have a certain resistance. When an aerial is "in tune" with the incoming wave it simply means that the inductive and capacity reactances of the aerial circuit are equal, and this will include not only the self-capacity and self-inductance of the aerial wire but also any tuning inductances and series or parallel tuning condensers. Under these conditions, the current which flows in the circuit is dependent solely on the resistance of the wires and consequently, in order to make an aerial system as efficient as possible, we should cut down to a minimum all resistances in the circuit

A numerical example will illustrate these points more clearly. Suppose that an aerial has a high frequency resistance of 10 ohms, and that it is tuned to a frequency of 500,000 (which corresponds approximately to 600 metres wave length) by means of a loading coil and a variable condenser which, together with the constants of the aerial wire itself, give a total inductance of 202·64 microhenrys and a capacity of 0·0005 microfarads.

The total impedance is now given by:

$$\sqrt{10^2 + \left(\frac{2\,\pi \times 500{,}000 \times 202{\cdot}64}{10^6} - \frac{10^6}{2\,\pi \times 500{,}000 \times {\cdot}0005}\right)^2}$$

$$= \sqrt{100 + [636{\cdot}6 - 636{\cdot}6]^2} = 10 \text{ ohms.}$$

Now let the circuit be slightly detuned by means of the variable condenser until the total capacity in the circuit is 0·00049 μfd. instead of 0·0005.

The impedance then becomes:

$$\sqrt{10^2 + \left(\frac{2\pi \times 500{,}000 \times 202{\cdot}64}{10^6} - \frac{10^6}{2\pi \times 500{,}000 \times {\cdot}00049}\right)^2}$$

$$= \sqrt{10^2 + [636{\cdot}6 - 649{\cdot}6]^2} = \sqrt{10^2 + 13^2} = \sqrt{269}$$

$$= 16{\cdot}4 \text{ ohms.}$$

The aerial current is thus reduced to two thirds of its maximum in-tune value, and note that the capacity reactance is 13 ohms. If, instead of being 10 ohms, the resistance of the aerial had been 1 ohm, then the effect of this detuning would have been to reduce the aerial current to about 1/13th of its original value, whilst, if the resistance of the aerial had been very high, then the increase in the capacity reactance would have had a correspondingly smaller effect. This is why the reduction of aerial resistance, either by the use of large section wire and a good earth connection or by the artificial method of using aerial reaction in the valve receiver, makes the tuning more critical or, as it is termed, "sharper."

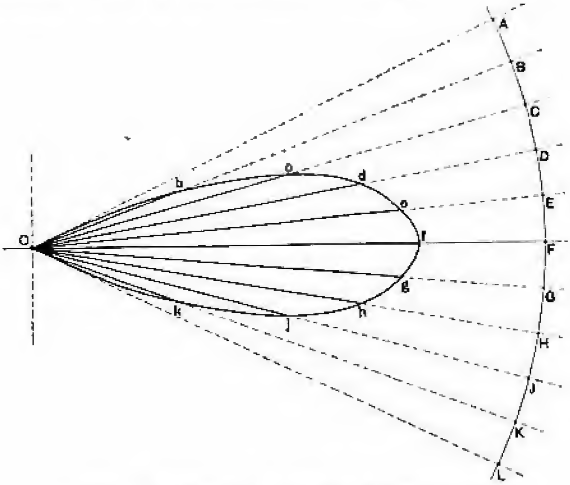


Fig. 42.—The use of Polar Co-Ordinates.

The reverse effect, namely that of adding resistance to an aerial, in order to "swamp" the reactance so that the current in the circuit may be more nearly in phase with the e.m.f. in spite of a large element of detuning, has an important application in the **resistance phased aerial** circuit of page 99.

The Polar Diagram or Space Pattern. In the study of Direction Finding it is convenient to have some method of illustrating graphically the receiving properties of an aerial system for various angles of incidence of the incoming wave. The scheme which seems the most logical and which is almost always adopted for transmitting or receiving aerials is the plane polar diagram. In Fig. 42, O represents the aerial system of a directive transmitter and it is desired to indicate how the radiation varies in different directions. A way of settling this point would be to take a portable receiver round the transmitter, keeping the receiver at a constant distance from the transmitting aerial, and to measure the strength of received signals at equi-distant angles all the way round. Then, if a series of radial lines from the point O be drawn, each line corresponding to one of the directions in which the strength of signals was measured, and if the *lengths* of these lines are made to correspond to the *intensity* of the received signal, the curve obtained by joining the extremities of all these lines will give a very clear picture of the performance and directional properties of the aerial system. In Fig. 42 we have supposed that the signal strength was measured at the points A, B, C, etc., and in each case a length has been marked off along the corresponding radius to represent the intensity of the signal so obtained, the points being joined up to form a smooth curve. Exactly the same graphical method can be adopted to represent the receiving properties of an aerial, which may vary according to the angle of incidence of the signals in just the same way that the transmitted signals vary in intensity.

Polar Diagram of a Vertical Open Aerial. From what has already been said concerning the way in which an e.m.f. is induced in an open aerial it will be clear that if the aerial be perfectly vertical, and the earth equally conducting in all directions, then the e.m.f. induced in the wire will be the same for equal intensities of field no matter what the horizontal direction of incidence may be. The polar curve of such an aerial will thus be a circle.

SPACED OPEN AERIALS AND THE SIMPLE FRAME

The bulk of direction finding is carried out by the use of aerial systems which depend for their directive effects on the properties of spaced aerials, the e.m.f.'s in which are combined in suitable receiving circuits. In Fig. 43 are shown two open aerials spaced half a wave length apart in the direction of travel of a wave, the instantaneous flux intensity of which is again shown by means of a sine curve. The combination of the two open aerial e.m.f.'s may be done by means of coupling coils with leads to a receiving station at the centre of the aerial system, and the various polar diagrams which are obtained for different spacings of the aerials are dealt with on page 72.

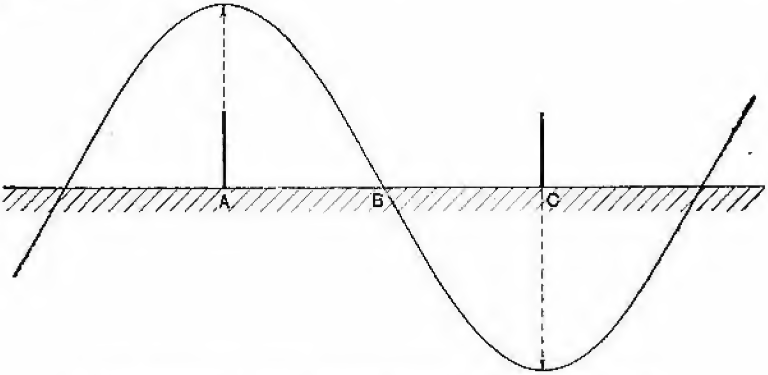


Fig. 43.—Open Aerials Spaced Half a Wave Length apart.

Suppose now that instead of combining the aerials at A and C, which are just half a wave length apart in the path of the wave, by means of intermediate circuits and a central receiver, we combine them as in Fig. 44. A lead is taken from the top of one aerial to the top of the other and a second lead having a coupling coil and tuning condenser in circuit joins the bottoms of the aerials which are now no longer earthed. The open aerials have now become a loop or frame, and notice particularly that the two e.m.f.'s in the vertical limbs of the frame at A and C, although in opposite directions relative to the earth, are *in the same direction round the frame* as indicated by the arrows, and since the e.m.f.'s at A and C are at maximum positive and negative values, there is maximum e.m.f. round the frame. Clearly the arrangement in Fig. 44 is not a practical one if it is desired to swing the frame for, assuming the wave length to be 1,000 m., then the distance between the side members would be 500 m. Also, although use is made of the fact that with half a wave length spacing there is maximum e.m.f. round the frame, there is the resistance of twice 500 m. of top and bottom connecting leads to be taken into account, and furthermore there would be difficulty in tuning such a large loop down to 1,000 m. wave length. In Fig. 45 the sides of the frame have been brought closer together and three positions for the small frame are shown, namely, at the instants when the flux at the centre of the frame is a maximum, when it is decreasing, and when it is zero. When the centre of the frame is at A, then, although the two e.m.f.'s in the side limbs are almost at their maximum values, they are acting *in opposite directions round the loop* so that their net effect is zero. A little later when the flux in the wave is decreasing, the e.m.f.'s are also less than before, but they differ in amplitude by an amount proportional to the length "x" in Fig. 45 (*a*), and this is the effective e.m.f. round the frame.

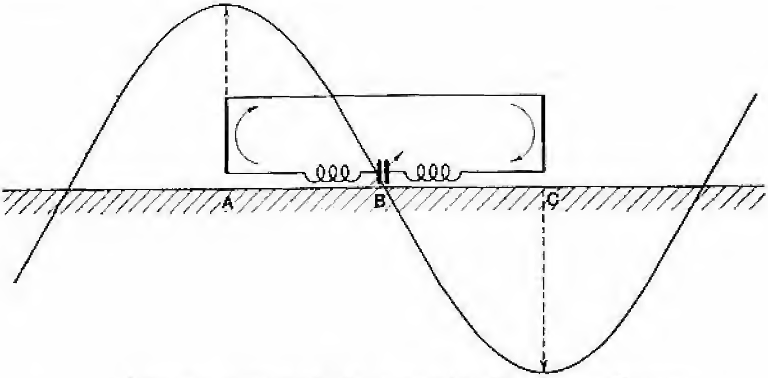


Fig. 44.—Aerials of Fig. 43 combined to form a Frame.

Owing to the fact that the effective e.m.f. in a frame aerial, receiving under these simple conditions, is always the algebraic difference of the e.m.f.'s in the vertical limbs, and in fact is proportional to the instantaneous rate of change of magnetic and electric force in the wave, it is often known as a **differential** e.m.f. Lastly, when the flux at the centre of the frame is zero, we see that although the e.m.f.'s in the side limbs are almost at their minimum values yet, owing to the fact that they are acting *in the same direction round the frame*, the frame e.m.f., which is proportional to "y," is a maximum for the given size of frame. The frame e.m.f. is thus seen to decrease as the width of the frame is made smaller and also *the frame e.m.f. is a quarter of a period out of phase with the flux in the wave.* These are extremely important characteristics of the frame aerial.

Flux Linkage and the Simple Frame. In the foregoing explanation the incoming wave has been assumed to produce an e.m.f. in each vertical limb of the frame, the active frame e.m.f. being the resultant of the two. This method of looking at the matter was chosen because it at once makes clear the phase difference between the wave and the e.m.f. which it produces and it is developed on page 72 with the aid of vector diagrams and simple mathematics to include the general case of two spaced open aerials. Now, the e.m.f.'s in the vertical limbs of the frame depend upon their height, and the active frame e.m.f. varies directly as the distance apart of the limbs when this distance is small compared to the wave length (page 74), so that the frame e.m.f. is proportional to the product of the height and spacing of the vertical limbs which is equal to the area of the frame. The amount of flux linked with the frame is proportional to the area and, in order to arrive at the polar curve of such an aerial, it is perhaps simplest to regard the e.m.f. as being a function of the flux linkage. Bearing this in mind, let us see how rotating the frame affects the e.m.f. and hence the received signals. Fig. 45 (*b*) is a

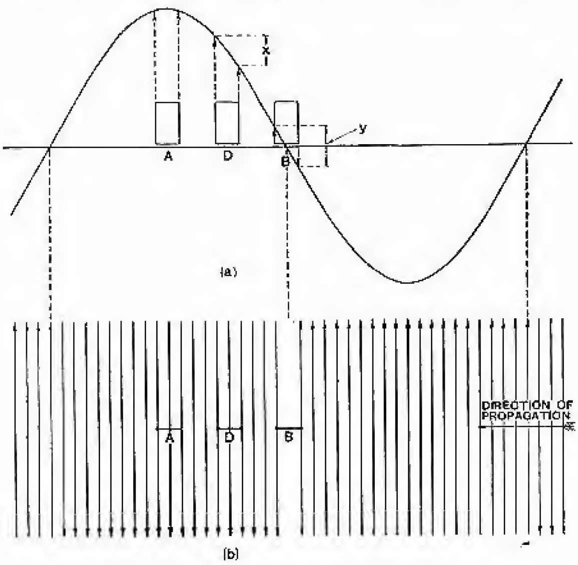


Fig. 45.—Elevation and Plan Views of Three Frames showing that the E.M.F. induced round a Frame is 90° Out of Phase with the Flux in the Wave.

view looking down on top of the arrangement in Fig. 45 (*a*), the varying intensities and directions of the magnetic flux being shown by a variation in the thickness and direction of the arrows. The three frames are all shown pointing in the direction of travel of the wave. Fig. 46 is an enlarged view of one of the frames and it has been assumed that the frame is so small in comparison with the wave length that the flux in the neighbourhood of the frame may be taken as uniform. It can be seen at once that the maximum number of lines are linked with the frame when it is pointing in the direction of travel of the wave, and that when it is rotated so as to be broadside on to the direction of travel then no lines are linked and there is consequently no induced e.m.f. and no received signal. The frame therefore possesses marked directional properties. The conditions existing at intermediate positions of the frame may best be illustrated by setting out the successive movements of the frame in a uniform magnetic field, and by counting the number of lines linked. In the position A A′ there are no lines linked; at B B′ there are 20; at C C′ there are 35; and 40 at D D′, after which the linkage begins to fall off again. There are 35 lines at E E′, 20 at F F′ and none when the frame reaches the position A′ A. The growth in linkage, and hence in induced e.m.f., now recommences; reaches a maximum at D′ D and falls to zero again at A A′. It is important to notice that although the same number of lines are linked at F′ F as at B B′, the lines do not pass through the frame in the same direction, as indicated by the curved

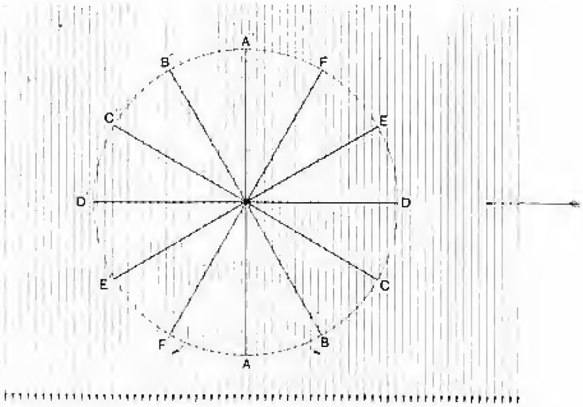


Fig. 46.—Variation in Flux Linkage as Frame is Rotated about a Vertical Axis.

arrows, and therefore *the e.m.f.'s induced will be in opposite directions round the frame.* This change occurs at A A′ and we thus see that when an alternating e.m.f. is being induced in a frame aerial by an incident wave, the phase of the e.m.f. will be shifted through 180° as the frame passes through the position of zero linkage.

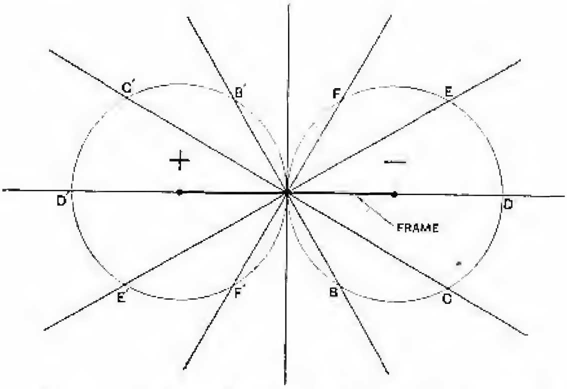


Fig. 47.—Cosine or Figure Eight Polar Diagram of E.M.F. induced in Rotating Frame.

Tabulating these results, we have:

Position of Frame.	AA′	BB′	CC′	DD′	EE′	FF′	A′A	B′B	C′C	D′D	E′E	F′F
Linkage or E.M.F.	0	+20	+35	+40	+35	+20	0	−20	−35	−40	−35	−20

one half of the values having been given a negative sign and the remainder a positive one in order to indicate the reversal of phase.

In Fig. 46 the successive positions of the frame were drawn 30° apart, so that if now a series of radial lines be drawn, with similar spacing, and the distances corresponding to the linkages in the respective directions be measured off along these lines to any convenient scale, the required polar diagram will be produced. When this is done, it is found that the points all lie on the circumferences of two circles as in Fig. 47, one of which corresponds to the positive values of linkage as found above and the other to the negative ones. The diagram is known as the **cosine** or **figure eight** diagram, and is characteristic of the simple frame aerial when the dimensions of the frame are small compared to the wave length. The simple mathematics of the frame aerial and the reason for the title "cosine" diagram will be found on page 74. The choice of the signs for the two halves of the diagram is purely arbitrary, but the distinction becomes very necessary when dealing with the production of the Cardioid or Heart-shape diagram of reception by the combination of the frame and open aerial receiving properties.

Once again it should be mentioned that although the properties of the frame aerial are being discussed in their relation to magnetic flux linkage, the whole subject may be treated equally well from the aspect of the electric force in the wave.

Maximum versus **Minimum Strength Signals for Direction Finding.** In practical direction finding, the accuracy with which a bearing can be taken depends to a great extent upon the sensitivity of the reception to small changes in the direction of the aerial. The figure eight diagram is very largely used for direction finding and a reading might be made either by noting the position of the frame when signals are loudest or by observing the direction corresponding to minimum signals. When the maximum strength is being observed, the frame is in the position D D′ in Fig. 46 and an inspection of the polar curve will show that a small change of angle will make a very small change in signal strength. If, on the other hand we take the position A A′, it is clear that a similar small change of angle will make a large percentage change of signal strength, as the curve is very steep around this position. The minimum is therefore very much more sharply defined than the maximum and it is possible to ascertain its position very accurately; hence it is customary in practice to arrange the direction finder so that, at the position of minimum signal streugth, the pointer attached to the rotating support of the

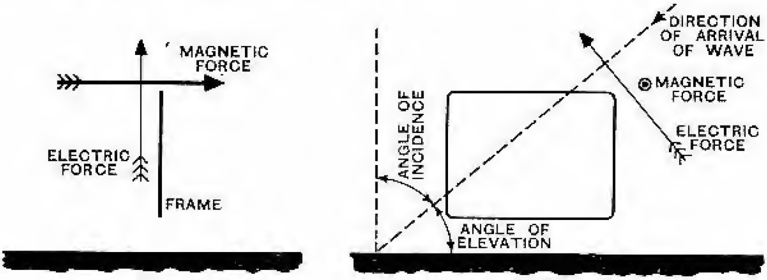


Fig. 48.—Frame in Position of Maximum Magnetic Linkage for Vertically Polarized Wave having Angle of Elevation.

aerial indicates on a circular scale, which is divided into degrees from 0° to 359°, the direction of the transmitting station.

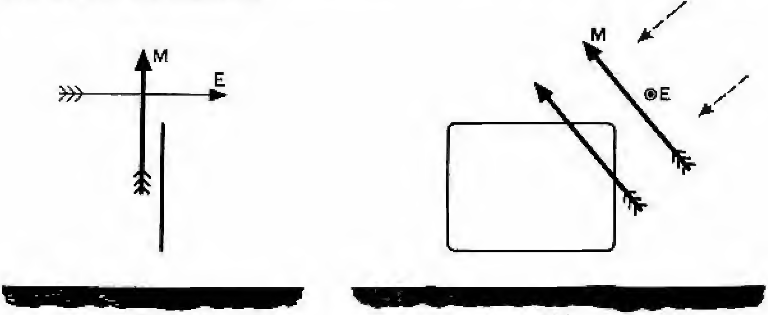
The minimum or zero of the cosine diagram is often referred to in American technical works as the "**null.**"

Effective Height of a Frame Aerial. The term "effective height" has been mentioned on page 57 in connection with the open aerial, and is somewhat unsuitable when applied to the loop. As before, however, it represents the factor which, when multiplied by the field strength in microvolts per metre, gives a measure of the e.m.f. generated in the loop in microvolts. It is given by:

$$h = \frac{2 \pi n A}{\lambda} \text{ metres}$$

where n = number of turns and
A = area of each turn in square metres.

It may be noted that the removal of the top horizontal member of a single-turn loop, and hence its conversion to a form of Adcock U aerial with unscreened lower limb, reduces the effective height of the system to 60% of the value given by the above expression.



(a) (b)

Fig. 49.—Frame in Position of Minimum Magnetic Linkage for Horizontally Polarized Wave having Angle of Elevation.

The Tilted Wave Front and Frame Reception. In Fig. 48 is shown a wave that is not travelling over the surface of the earth but is arriving at a receiving frame with an **angle of elevation** of about 40°, (a) and (b) being respectively the end and side views of the frame. The angle of elevation is measured from the horizontal, its complement measured from the vertical being the **angle of incidence.** The wave is normally (that is to say vertically) polarized, and as a reminder of this one arrow in the vertical plane of propagation of the wave has been drawn to represent the electric force in addition to the arrow representing the magnetic force, and, as in the case of a wave moving along the ground, the maximum linkage with the lines of magnetic force is obtained when the frame is in the position shown, that is, having its plane in the vertical plane of propagation of the wave. Since the controlling effect of the earth's surface can no longer operate in the case of a wave travelling in free space, and particularly since there are factors tending to rotate the plane of polarization, such a wave may have a large component which is abnormally polarized. Fig. 48 has therefore been redrawn in Fig. 49 in which the whole of the magnetic flux is in the vertical plane of propagation of the wave, and one line of magnetic flux is shown passing the frame but, since both are in the same vertical plane, there will be no cutting of the frame by the flux and hence no induced e.m.f. When, however, the frame is turned so as to have its plane at right angles to the plane of propagation of the wave, as shown in Fig. 50, there is maximum linkage between the upper and lower limbs and hence maximum induced e.m.f. The directional properties of the frame are now vested in the spacing of the horizontal limbs and the polar diagram is a figure eight which has its *minimum in the direction of the plane of the frame* as in Fig. 51. Compare this with

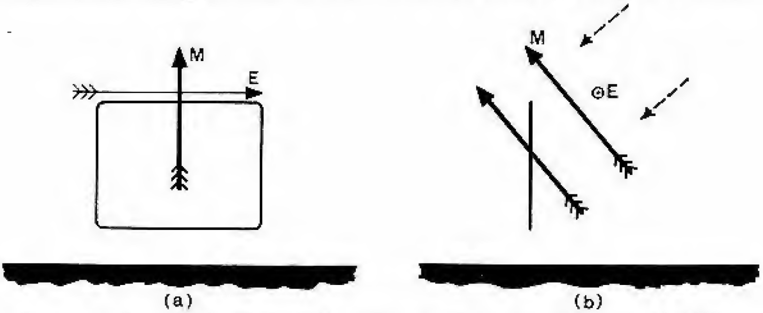


Fig. 50.—Frame in Position of Maximum Linkage for Wave as in Fig. 49.

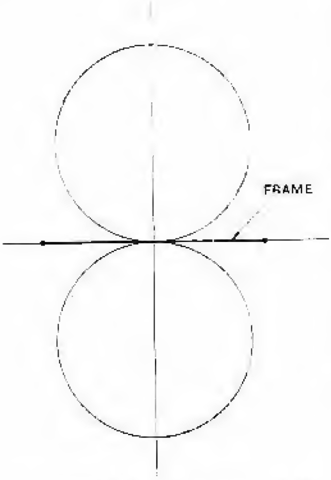


Fig. 51.—Polar Diagram of Reception of wave as in Figs. 49 and 50, by Frame Rotating about a Vertical Axis.

Fig. 47 for the normally polarized wave. Clearly, if an attempt were made by means of a simple frame to find the direction of a station which was radiating such a wave as this, an error of 90° would result.

The further consideration of these errors, which are such a serious problem in wireless navigation, is taken up again in Chapter 6 on Polarization Errors and Night Effect.

The Cardioid or Heart-shaped Diagram of Reception. It has been seen that two minima are obtained with the simple frame aerial so that, supposing a bearing of 45° has been obtained, there will also be a further possible value for the bearing at 45° + 180° = 225°, and it is quite impossible, using the cosine diagram alone, to decide which of the two is correct. In many cases such information is not necessary, other evidence indicating which is the reading to take, but it is often of great value to have this information, and modern direction finding installations are usually equipped with means of determining absolute direction or "**sense.**"

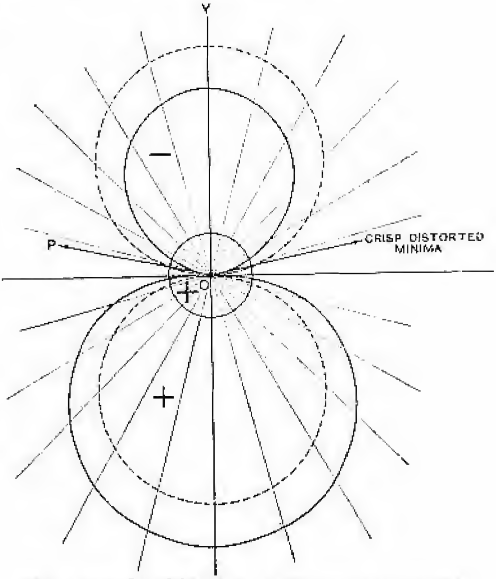


Fig. 52.—Combination of Polar Diagrams of Reception of Frame and Open Aerial.

By combining the receiving properties of the open aerial and the frame, a new series of diagrams is obtained, one of which is of great value for sense determination. In Fig. 52 the two dotted circles are the figure eight of the frame and the smaller circle with its centre at O is the open aerial diagram. If we assume that the two e.m.f.'s represented by these diagrams are combined in a single receiver and are in phase, then the total e.m.f. induced in the circuit of the receiver will be given by the algebraic sum of the component e.m.f.'s for any particular orientation of the frame, and the new diagram of reception for the combination will similarly be given by the algebraic sum of the circle and figure eight diagrams. On page 64 it was shown that the phase of the e.m.f. round a frame shifts abruptly through 180° when the frame passes through minimum signal position, whilst no such shift in phase can occur in the case of the open aerial. Consequently, when combining the diagrams, one circle of the figure eight must be regarded as positive and the other as negative, the small open aerial circle being either sign. The choice of signs is, of course, purely arbitrary so long as they bear the correct relation to one another. If now the polar ordinates are added graphically, the complete diagram will be that shown by the full line.

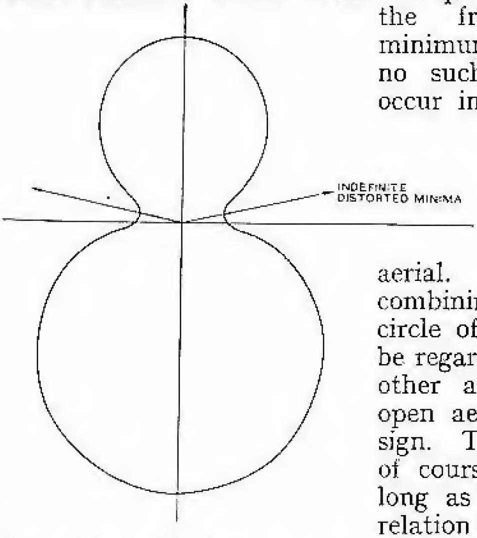


Fig. 53.—Resultant of Fig. 52 when Components are not in Phase.

This resultant is only obtained when the two e.m.f.'s are exactly in phase (or phase opposition). If they have any intermediate phase relation there will be no sharp zero values in the resultant diagram for, although when the plane of the frame is in the direction O Y and the incident signal along P O, the maximum values of the radio frequency e.m.f.'s induced in the frame and open aerials may be equal, they will not reach their maximum amplitudes at the same instant and so can never balance one another out. The resultant diagram in such a case would be as in Fig. 53, the actual shape of the minima depending on the degree of phase difference of the component e.m.f.'s. The in-phase condition, however, gives definite zero values, and if the size of the circle diagram be gradually increased relative to the figure eight then, as seen in Fig. 54, the positions of the minima become more and more distorted until finally in Fig. 54 (*c*), when the open aerial and frame e.m.f.'s are equal in amplitude, they merge into one and we obtain what is called the cardioid diagram. Any further increase in the open aerial e.m.f. gives a single impure minimum. It will be seen that in the cardioid diagram the maximum is 180° away from the minimum, so that if it be used for direction finding there is no longer any ambiguity as to the actual direction of a transmitting station. If the frame be rotated, only one point can be found on the scale at which the signals vanish. It should also be noted that the maximum of the heart-shape diagram is twice the strength of the maximum of the frame aerial alone and, further, that the minimum of the heart-shape is in the plane of the frame and 90° away from the minimum of the figure eight diagram of the frame alone.

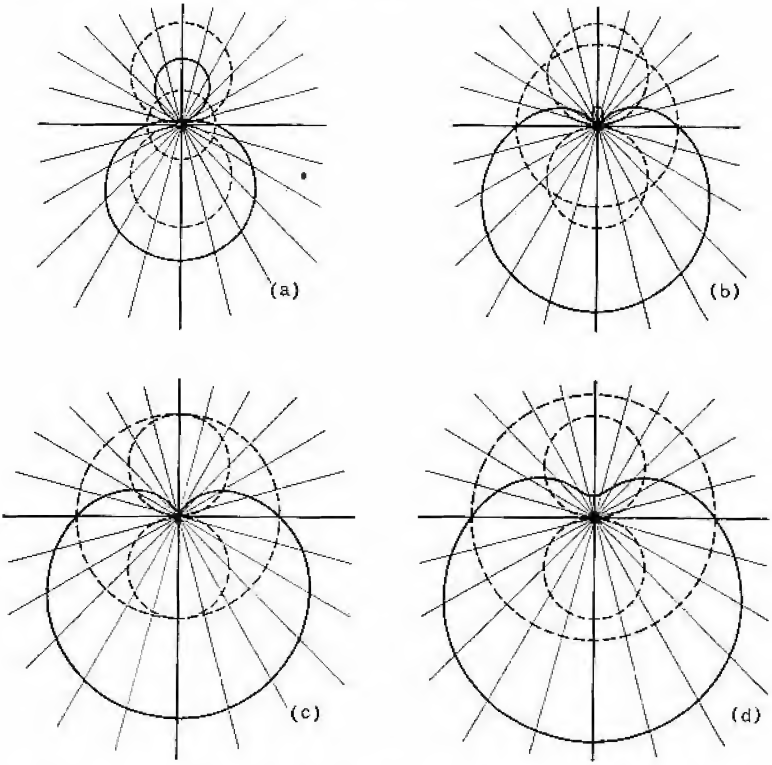


Fig. 54.—Evolution of Cardioid or Heart-Shaped Diagram by Combination of Circle and Cosine Diagrams with Correct Phase Relations.

Unilateral Reception. When the circuit is adjusted so as to give a diagram such as in Fig. 54 (*a*), (*b*) or (*d*) the result is often referred to as **unilateral** reception, meaning, in this connection, that there is enough asymmetry to indicate sense but that a true cardioid is not necessarily obtained.

GENERAL CASE OF TWO SPACED OPEN AERIALS*

On page 8 it was pointed out that the properties of combinations of spaced aerials play an important part in almost all directional receiving systems, and it is of particular interest to study the elementary mathematics of such systems and to observe how the simple frame is actually a special case of two spaced aerials, in which the spacing is small compared to the wave length of the signal received. Studied from this point of view more information can be obtained concerning the frame and a foundation laid for investigations of far more complex aerial systems which cannot conveniently be described or understood by the more elementary method of flux linkages.

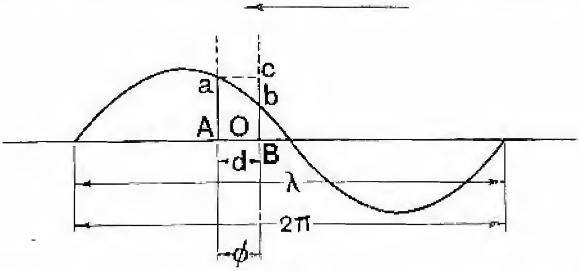


Fig. 55.—Two Open Aerials Spaced in Direction of Travel of Wave.

Central Summation with Effects in Opposition. In Fig. 55 are shown two open aerials A and B, spaced a distance *d* apart in the wave of length λ. The instantaneous values of the field strength in the wave are represented by the ordinates Aa and Bb of the conventional sine curve and the direction of propagation by the arrow. Let O be the point midway between the aerials, at which point is a receiver in which the e.m.f.'s induced in the two aerials are combined by means of appropriate circuits. Calling the spacing of the aerials ϕ, where $\phi = \frac{2\pi d}{\lambda}$, we can draw a vector diagram to illustrate the relative phases and intensities of the e.m.f.'s and currents in the aerials and of the resultant e.m.f.'s in the receiving circuit.

In Fig. 56, OO′ represents the phase of the centre point of the aerial system or, in other words, we will reckon time from the instant the wave front arrives at O in Fig. 55. Now the wave reaches the aerial B earlier than the point O by a time proportional to $\phi/2$, and similarly it reaches A $\phi/2$ later than O. E_b, therefore, represents the e.m.f. in the B aerial which is shown leading on OO′, assuming counter-clock rotation of the vectors, and E_a is the lagging e.m.f. in the A aerial, both being $\phi/2$ out of phase with OO′. If now the associated circuits be so arranged that the aerial currents I_b and I_a, which are in phase with their respective e.m.f.'s, induce e.m.f.'s E'_b and E'_a in a common receiving circuit and, further, that these two e.m.f.'s are in opposition to one another, then we have the case shown in the diagram where E'_b and E'_a are lagging 90° on the currents which are inducing them and E'_b has been reversed before obtaining the resultant E_r. Since the total phase difference between E'_b and E'_a is ϕ, the resultant is proportional to:

---

* The remainder of this chapter may be omitted by a student at the first reading without affecting the continuity of the subject.

$$\sqrt{E_v^2 + E_v^2 - 2\,E_v^2 \cos\phi}.$$

where E_v is the e.m.f. induced in either aerial.

This is equal to:

$$\sqrt{2E_v^2\,(1 - \cos\phi)}$$
$$= \sqrt{2}\,E_v\,\sqrt{(1 - \cos\phi)},$$

from which we see that the resultant e.m.f. is a maximum when $(1 - \cos\phi)$ is a maximum, that is to say, when $\cos\phi$ is equal to -1 and $\phi = 180°$. In other words, the resultant e.m.f. is a maximum and equal to $2\,E_v$ for a spacing of half a wave length, $1\tfrac{1}{2}\lambda$, $2\tfrac{1}{2}\lambda$, etc., and is zero for zero spacing and also for a spacing of a wave length or a multiple of a wave length.

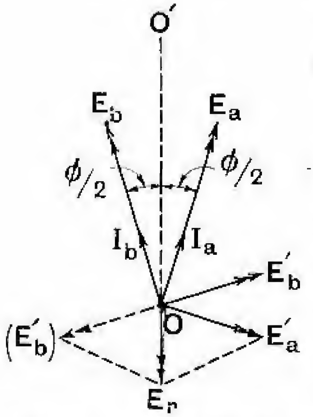


Fig. 56.—Vector Diagram for Two Open Aerials of Fig. 55.

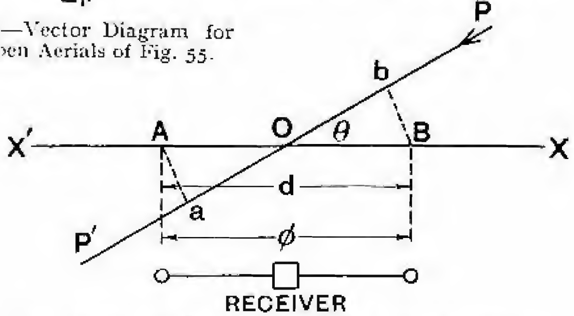


Fig. 57.—Plan View of Two Open Aerials Spaced in Direction making an Angle with Direction of Travel of Wave.

Theory of the Cosine Diagram. The above condition is that in which the aerials are spaced in the direction of travel of the wave, but the important case is that in which the wave has any other horizontal angle of incidence. Let Fig. 57 represent a plan view of two spaced aerials in which the direction of an incident wave is along the line POP′, making an angle θ with the line of the aerials XOX′. In this case O*b* will be a measure of the leading phase of the e.m.f. in B, where B*b* is a perpendicular dropped on the line POP′. Similarly O*a* is the lag in the A aerial and the total phase difference is *ab* which is equal to $d \cos \theta$ or $\phi \cos \theta$ where $\phi = \frac{2\pi d}{\lambda}$.

The diagram showing the vector difference of e.m.f.'s for these conditions is the same as in the previous case, Fig. 56, except that the angles of lag and lead of the e.m.f.'s in A and B are $\frac{\phi}{2} \cos \theta$ instead of $\phi/2$. The resultant E_θ is therefore :

$$\sqrt{2 E_v^2 [1 - \cos(\phi \cos \theta)]}$$

$$= \sqrt{4 E_v^2 \sin^2 (\frac{\phi}{2} \cos \theta)}$$

$$= 2 E_v \sin (\frac{\phi}{2} \cos \theta)$$

where E_v is the value of the e.m.f. in either aerial.

In Fig. 58 curves are shown for a number of values of ϕ and it will be noticed that as the spacing becomes small compared with the wave length, the polar diagram approaches in shape that of the " figure eight " or cosine diagram. This is clear from the expression above, for, when ϕ is small, $\frac{\phi}{2} \cos \theta$ is also small and we may write :

$$\text{Sin} (\frac{\phi}{2} \cos \theta) = \frac{\phi}{2} \cos \theta.$$

Therefore : $E_\theta = 2 E_v \frac{\phi}{2} \cos \theta = E_v \phi \cos \theta,$

which means that the maximum value of the resultant e.m.f. is reduced to a small value equal to ϕE_v or $\frac{2 \pi d E_v}{\lambda}$, and it follows the cosine law for various values of θ. As θ passes through 90° the e.m.f. in the B aerial in Fig. 57 will cease to lead on that in A and will lag, so that there will be a complete reversal of phase as the resultant e.m.f. passes through its zero value and the quadrants in Fig. 58 may be marked + ve and — ve as shown.

Observe that the assumption which has been made above, that ϕ is sufficiently small to take $\phi/2$ as being equal to sin $\phi/2$ thus making E_θ proportional to cos θ, is exactly the same as the assumption which was made on page 64 that the flux in the neighbourhood of our rotating frame was sufficiently uniform for the flux linkage to be proportional to the cosine of the angle of rotation. The abrupt change in phase of the e.m.f. round the frame as it passes through the position of minimum is now seen to be due to the fact that as the angle θ passes through 90°, the e.m.f. in B ceases to lead on that in A and lags instead.

The vector diagram for the simple frame is as shown in Fig. 59 where the aerial e.m.f.'s E_a and E_b are opposed to one another, and it will now be noticed that the resultant e.m.f. E_θ, round the frame, lags 90° on the flux in the wave, and this is a characteristic of the frame aerial.

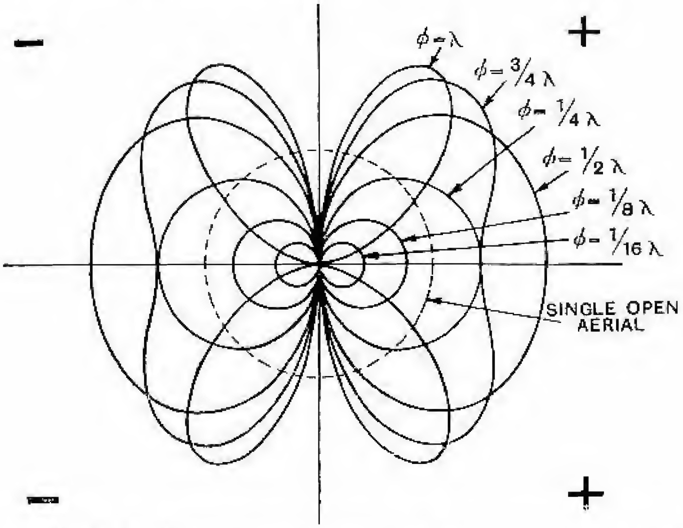


Fig. 58.—Polar Diagrams of Reception for Two Open Aerials with Various Spacings.

Non-Central Summation and the Theory of the Cardioid Diagram. The method described on page 72 of combining the effects in the spaced open aerials may be termed "Central Summation," in that the receiving circuit is situated electrically mid-way between the aerials; the individual aerial currents are in phase with their respective e.m.f.'s and hence any out of phase effect between the two e.m.f.'s induced in the receiving circuit is purely a function of the spacing of the aerials in the path of the wave, and is not an artificially obtained effect.

Now, in certain circumstances, it may be necessary to arrange for a phase relation between the e.m.f.'s in the receiver which is not to be obtained by central summation, and a case of this is the Cardioid diagram shown in Fig. 62. Here we wish to provide for the two e.m.f.'s in the receiving circuit to be in complete phase opposition when the angle θ is zero and to be in phase when θ is 180°. In order to achieve this result, consider the arrangement in Fig. 60, in which the receiver is placed at the foot of the A aerial instead of mid-way between the aerials. Constructing a vector diagram, Fig. 61, let OA be the phase of the new centre of the system, or, in other words, let us reckon the time from the instant at which the wave reaches the A aerial. This will be the phase of the e.m.f. in A so we can draw E_a. The e.m.f. in B when θ is zero, will lead on that in A by an amount ϕ, owing to its spacing ϕ in the direction of incidence of the wave. The receiver is, however, at A and when the e.m.f. E_b has been impressed upon the pair of lines from the base of the B aerial to the receiver, the time taken for the current wave to travel to the receiver will be practically the same as that taken by the propagated electromagnetic wave to travel from the aerial B to the aerial A, the net result being that the two aerial current effects will reach the receiver together. By a simple circuit arrangement, these two currents can be made to induce e.m.f.'s E'_a and E'_b in the receiver circuit, equal in amplitude and opposite in phase, resulting in zero reception. For any other angle of incidence θ, the spacing of the aerials in the path of the wave will be $\phi \cos \theta$ so that the e.m.f.

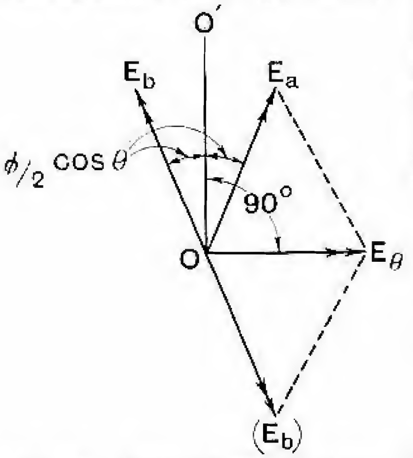


Fig. 59.—Vector Diagram for Frame Aerial showing Frame E.M.F. Lagging 90° on Flux in Wave.

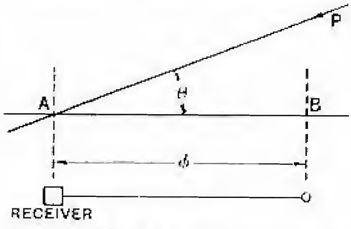


Fig. 60.—Plan View of Two Spaced Open Aerials in which Special Phase Relations are obtained by Non-Central Summation.

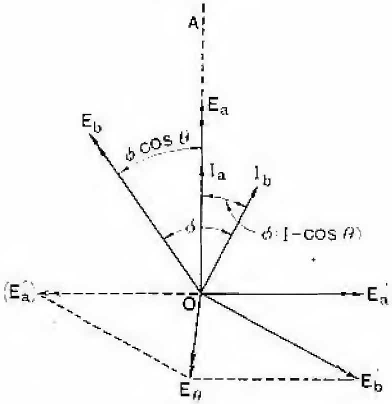
in B will lead on that in A by that amount. The time taken for the B effect to travel from B to A will, however, be the same as before, so that the net phase difference of the effects in the receiver will be $\phi\cos\theta-\phi$ or $\phi\ (\cos\theta-1)$. Reversing one of the vectors and adding, we get the resultant E_θ which is given by:

$$\sqrt{2\ E_v^2\ [1-\cos\ \phi(\cos\theta-1)]}$$

and as before, for small values of ϕ, this simplifies down to:

$$E_v\ \ \phi(\cos\theta-1)$$

which when plotted gives the polar curve of Fig. 62.



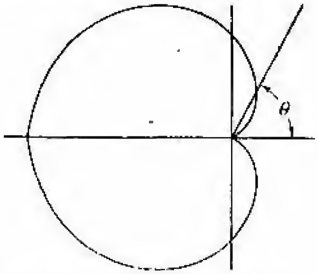


Fig. 62.—Cardioid or Heart-Shaped Polar Diagram.

Fig. 61. (Left)—Vector Diagram for Two Open Aerials of Fig. 60.

The case in which the cardioid diagram is obtained by central summation combined with mis-phasing of the aerial currents, or by the use of artificial transmission lines to retard the currents and produce the requisite phase relations, is described in Chapter 4, since it deals with the circuits employed rather than the fundamental directional properties of the aerial systems.

SPACED FRAME AERIALS

The case of spaced open aerials may be extended very simply to cover spaced frames which have some application in directive reception and are mentioned again on page 124.

Coplanar Spaced Frames. Central Summation. In Fig. 63 are shown two frame aerials spaced ϕ apart and with their planes in the vertical plane through XOX'. Just as in the previous case of spaced open aerials, a wave incident along the direction PO will reach the B aerial earlier and the A aerial later than it does the mid-point O of the system. Furthermore, the resultant e.m.f.'s round the frames will each lag 90° on the flux in the wave so that the resulting e.m.f.'s will lag respectively ($90° - \phi/2 \cos\theta$) and ($90° + \phi/2 \cos\theta$) on the centre point O. It must also be remembered that in addition to the directional effect due to the spacing of the frames, the e.m.f. in each frame is itself dependent on the angle of incidence and the dimensions of the frame. Thus, for any angle θ, and width of frame ϕ, the e.m.f. in each frame is $E_v \ \phi \cos \theta$ so that the vector diagram for the central summation of the two frames is as in Fig. 64 where :

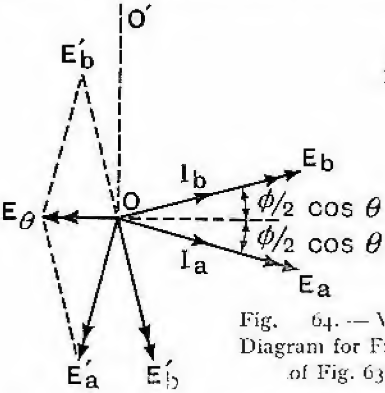


Fig. 64. — Vector Diagram for Frames of Fig. 63.

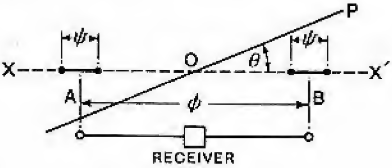


Fig. 63.—Plan View of Two Co-Planar Spaced Frames with Central Summation.

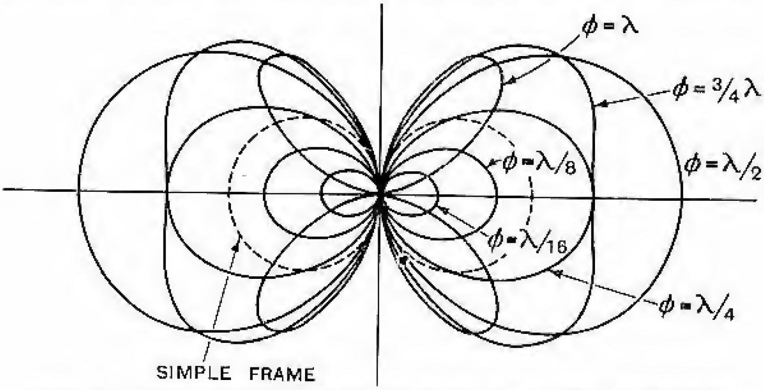


Fig. 65.—Polar Diagrams of Reception for two Co-Planar Frames, as in Fig. 63, with Various Spacings.

OO' is the phase of the flux in the wave
E_b is the e.m.f. in B, lagging ($90° - \phi/2 \cos\theta$) on OO'
E_a is the e.m.f. in A, lagging ($90° + \phi/2 \cos\theta$) on OO'

I_b and I_a are the aerial currents
E'_b and E'_a are the e.m.f.'s induced in the receiver circuit
E_θ is the resultant of E'_a and E'_b reversed and is given by :

$$\sqrt{2 E_v^2 \psi^2 \cos^2 \theta - 2 E_v^2 \psi^2 \cos^2 \theta \, [\cos (\phi \cos \theta)]}$$
$$= E_v \psi \cos \theta \sqrt{2 \, [1 - \cos (\phi \cos \theta)]}.$$

Curves are shown in Fig. 65 for various values of spacing from $\phi = \lambda$ to $\phi = \lambda/16$.

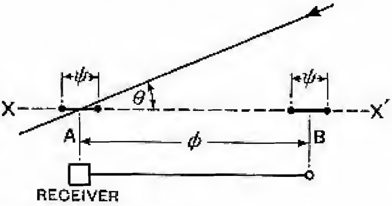


Fig. 66.—Plan View of Co-Planar Spaced Frames in which Special Phase Relations are obtained by Non-Central Summation.

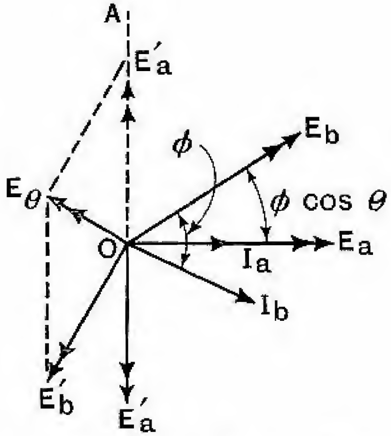


Fig. 67.—Vector Diagram for Frames of Fig. 66.

Coplanar Spaced Frames. Non-Central Summation. Now consider the case when the current due to the e.m.f. in the B frame is arranged to lag by an amount ϕ on the e.m.f., summation being carried out at the base of the A aerial as shown in Fig. 66. For $\theta = 0°$, the conditions will now give a zero balance when the circuit is adjusted so that the e.m.f.'s are in opposition and the general case is illustrated in the vector diagram of Fig. 67 where :

OA is the phase of the flux in the wave at A
E_b is the e.m.f. in B, lagging $(90° - \phi \cos \theta)$ on OA
E_a is the e.m.f. in A, lagging 90° on OA
I_b is the current due to B, lagging ϕ on E_b
I_a is the current due to A, in phase with E_a
E'_b and E'_a are the e.m.f.'s induced in the receiver circuit
E_θ is the resultant of E'_b and E'_a reversed.

The net phase difference between E'_b and E'_a is therefore $\phi (\cos \theta - 1)$ and the resultant E_θ is given by :

$$E_v \psi \cos \theta \sqrt{2 \, [1 - \cos \phi (\cos \theta - 1)]}$$

Fig. 68 shows the polar diagrams for such systems with spacings varying from $\phi = \lambda$ to $\phi = \lambda/16$.

Parallel Spaced Frames. In addition to coplanar frames, the parallel arrangement of Fig. 195 is also used and the relative advantages of the two systems are mentioned in later chapters.

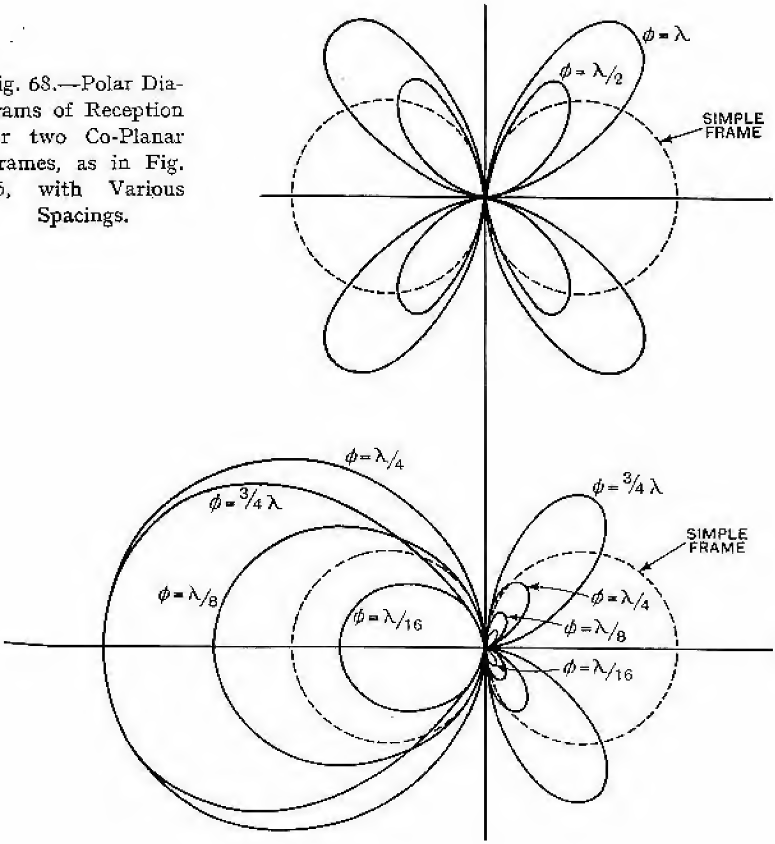


Fig. 68.—Polar Diagrams of Reception for two Co-Planar Frames, as in Fig. 66, with Various Spacings.

Further cases of polar diagrams of spaced aerials are given in (1001), (2614), (2619), (3622) and (3702).

CHAPTER 4

FRAME AERIAL RECEPTION

In Chapter 3 it was seen that the directional properties of the frame aerial for normally polarized waves are vested in the vertical limbs of the frame, and in the early days of wireless reception a number of systems were evolved which consisted of combinations of vertical aerials, arranged to give polar diagrams of reception very similar to the figure eight diagram described previously.

Although spaced open aerials are being used to an increasing extent, mobile D.F.'s, as used in ships and aircraft and for portable work, make use almost exclusively of frame aerials and may be grouped under headings somewhat as follows :

(1) Small frame aerials connected directly or through an intermediate circuit to an amplifier and detector.

(2) Combinations of frame aerials, fixed relatively to each other but free to rotate as a whole and with or without switching arrangements for the summation of the aerial e.m.f.'s.

(3) Fixed frame aerials with an associated radiogoniometer (page 138), which enables the rotating part of the system to be reduced to small dimensions.

The frame aerial may also be used in conjunction with a vertical aerial for the production of a cardioid diagram, this being applicable both to the small rotating frames and also the fixed frame and radiogoniometer, as in the Bellini-Tosi system.

CAUSES OF DISTORTED COSINE MINIMA

It is necessary to investigate, first of all, certain troublesome features of frame aerial reception which are common to all types of frame, both single and multi-turn, whether used as a rotating frame D.F. or as large fixed loops in conjunction with a radiogoniometer.

The circuit of the simple rotating frame D.F. is shown in Fig. 69, in which the valve amplifier is connected directly across the tuning condenser of the coil. Alternatively, a coupled circuit may be used, the aerial coupling coils being split for the insertion of the tuning condenser in order to maintain the symmetry of the circuit as in Fig. 70.

Although the theoretical polar diagram of a frame aerial suggests, at first sight, a complete solution of the problem of direction finding, a number of serious defects are discovered when such an aerial is used for the purpose in practice. The most common of these is the distortion of the normal figure eight diagram in the manner already shown in Figs. 52 and 53. This distortion is characteristic of the frame aerial, and may be taken as applicable to all systems of D.F. in which any type of frame is used.

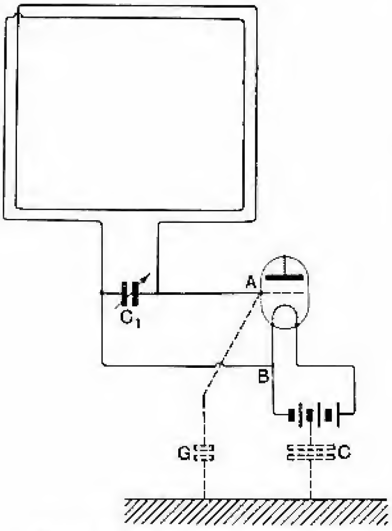


Fig. 69.—Circuit of Simple Frame D.F.

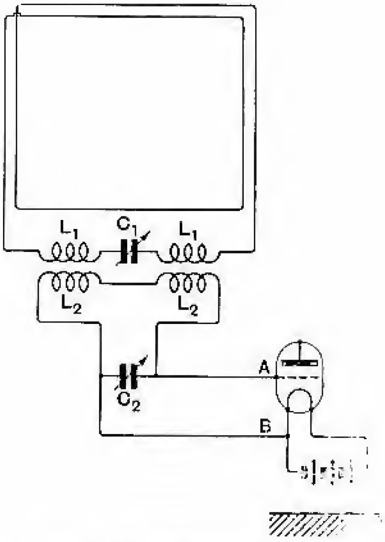


Fig. 70.—Simple Frame D.F. with Coupled Circuit.

The distortion is due to four or more possible causes :

(1) The tendency of the loop aerial to oscillate direct to earth, as a whole, through the capacity of the receiver. This phenomenon is known as "**Antenna Effect,**" "Electrostatic Error," "Vertical Component" or simply "**Vertical.**"

(2) Direct reception of signals on the receiver circuit, apart from the energy received on the aerial, and which is called "Direct reception" or more commonly, "**Pick-Up.**"

(3) **Quadrature Effect** due to mis-phased re-radiation from conductors near the loop. Quadrature effect is not actually an inherent defect of the loop, but may conveniently be studied at this point.

" Night Effect," another external cause of indefinite minima, is discussed later.

(4) **Displacement Currents** due to the capacity of a solenoid form of loop.

Antenna Effect or Vertical.

In Fig. 45 it was seen that the maximum e.m.f. round a frame aerial existed at the instant at which the flux in the wave was zero and the two individual e.m.f.'s in the side limbs of the frame were very small. When these e.m.f.'s in the side limbs are at a maximum, they are opposing one another round the frame, so that there should be no received signal. Notice that at this instant, these two e.m.f.'s are very many times greater than the differential frame e.m.f. even at its maximum, and it is these very large e.m.f.'s acting together up and down the sides of the frame which force their way through to the receiver and cause the minima to be indefinite or not diametrically opposite. Any signal which is heard is caused by a potential difference across the frame tuning condenser and it has been seen how this potential difference can be reduced to zero when the frame is turned broadside on to the wave, so that there is no linkage of flux with the frame or, in other words, so that the two e.m.f.'s in the side limbs are exactly equal and in phase with one another. Even when the frame is in this position, however, the large e.m.f. s in the side limbs are still there and are tending to force currents to earth via the two points A and B in Fig. 69. Now, the point B is joined to the filament batteries which will have an appreciable capacity to earth as shown in the diagram by the dotted condenser C, or they may be actually metallically connected to earth. On the other hand the A terminal is only attached to the grid of the first valve, which has a very small capacity indicated by the condenser G, so that the path to earth from the B leg of the frame is of much lower impedance than the A path. There will hence be a difference of potential between A and B *regardless of the position of the frame.*

If the frame be magnetically coupled to the receiver as in Fig. 70, instead of being directly connected, then the coupled circuit is tuned by means of a second condenser C_2 across which the valve amplifier is connected as before. The coupling coils L_1 and L_2 may also be considered as being the field coil and search coil of the radiogoniometer used in the Bellini-Tosi system. So long as the coupling between L_1 and L_2 is fairly tight, there will be an appreciable capacity between the two circuits which is more or less uniform along the windings. Owing to the different impedances of the paths to earth through A and B, different currents will flow down them, so that the fall in potential through the winding from the mid point of L_2 to A will not be the same as that to B, and a difference of potential will therefore exist across condenser C_2 with consequent vertical effect.

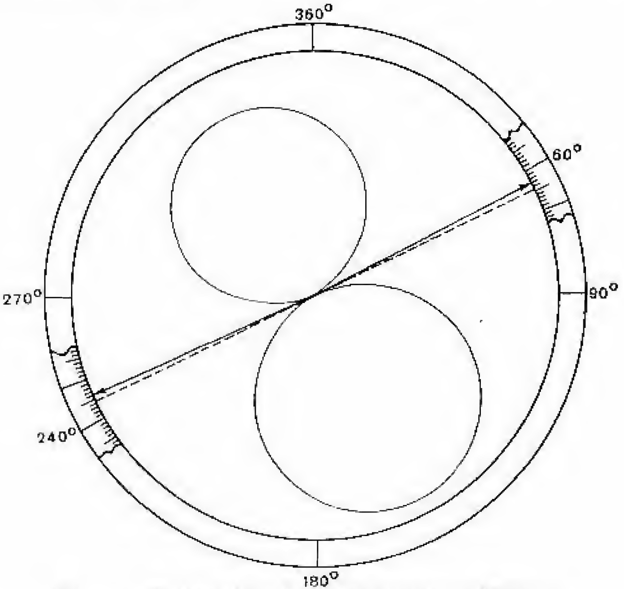


Fig. 71.—Distorted Scale Readings due to Vertical.

Polar Diagram of Figure Eight Distorted by Vertical Effect. The result of antenna effect is that an e.m.f. is applied to the amplifier which is independent of the direction in which the loop is pointing. If the phase of the effect happens to be nearly coincident with the normal loop e.m.f., the minima are sharp but displaced as shown in Fig. 52, but if the phases differ, the minima are more or less displaced and are impure. The polar diagram of a frame plus out-of-phase vertical is shown in Fig. 53, where it will be seen that no actual zero of signal occurs at any place. If a direction finder suffers from much out-of-phase vertical it will be readily understood that it is very difficult to take directions at all, but it is important to notice that, if the minima are fairly pure, the correct bearing can usually be found by making allowance for the vertical. Thus, in Fig. 71, suppose the two scale readings of a figure eight bearing were 63° and 246° it would in most cases be perfectly safe to assume that the correct figures were $64\frac{1}{2}$° and $244\frac{1}{2}$°, which are obtained by adding and subtracting respectively $1\frac{1}{2}$° so as to bring the two readings 180° apart on the scale. This would only be an emergency measure, and steps should be taken to get rid of the 3° of vertical.

A point to be borne in mind in the practical use of the frame aerial is that the amplitude of the vertical effect is independent of the tuning of the frame itself so that, if the loop is slightly mis-tuned, the ratio of vertical to loop signal in the receiver may be greatly increased with consequent increase in the distortion of the diagram.

The intensity of the vertical reception varies approximately as the linear dimensions of the loop, whereas the loop receiving power is proportional to the square of the linear dimensions; so that the larger the frame is made, the less will be the effect of vertical.

Grid Condenser, Balancing Condenser or "Compensator" Method of Eliminating Vertical. Vertical has been seen to be due to the unbalanced capacity to earth of the amplifier input circuit. The most immediate way of correcting the trouble is to make these two capacities exactly equal, and this can be done by connecting a small condenser from the grid of the first valve to earth, which is equivalent to putting a condenser in parallel with G in Fig. 69. This is adjusted in value until the total capacity of G and the extra condenser is equal to C. When this is the case there can be no potential induced across the condenser C_1, except due to the loop e.m.f., because the two parallel paths to earth have equal impedance.

Fig. 72 shows the use of a differential balancing condenser in which the two sets of fixed vanes are connected to grid and filament respectively and the moving plates to earth. In some cases better results may be obtained by connecting the moving vane to an open aerial as shown by the dotted lines. When this is found to be the case, Quadrature Effect may possibly be present either alone or in addition to vertical, and this point is dealt with later.

Push-Pull Valve Circuit. A suggested means of obtaining symmetry in the D.F. receiving circuit by means of a Class B type valve is mentioned by Kolster and Dunmore (2201), and is illustrated in Fig. 73.

Earthed Mid-Point of Frame Coupling. Another method is to apply an earth connection to the mid-point of the aerial coupling coil as shown in Fig. 74, where it will be seen that the loop is broken at the centre for the insertion of the tuning condenser C_1. The two halves of L_1 are directly joined in series and the mid-point earthed. By this means, the potential of the coil L_1 is kept at zero with respect to the earth. There is thus a direct path to earth for the vertical effect, and the distributed capacity between the coupling coils is short-circuited; consequently no capacity currents flow in L_2 and no e.m.f. is produced by vertical effect across the condenser C_2.

This method is very effective, but not perfect, in practice. The residual vertical is due to two causes:

(1) Imperfections in the earth connection and also the inductance of the earth lead both allow the coils to vary slightly in potential.

(2) Owing to the inductance of the two halves of the coil, even if the centre point is at zero potential, the ends of the coil may not be so.

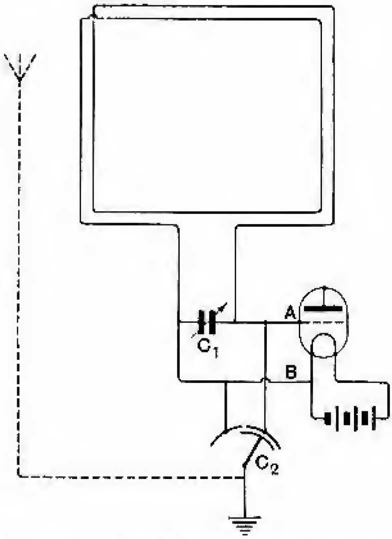


Fig. 72.—Three-Plate Balancing Condenser for Reduction of Vertical.

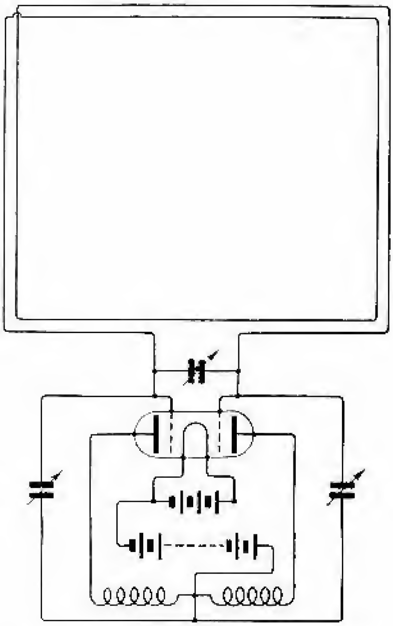


Fig. 73.—Push-Pull Valve Circuit for Reduction of Vertical.

The method is, therefore, generally used in conjunction with other means and is regarded more as an additional safeguard than as a positive cure.

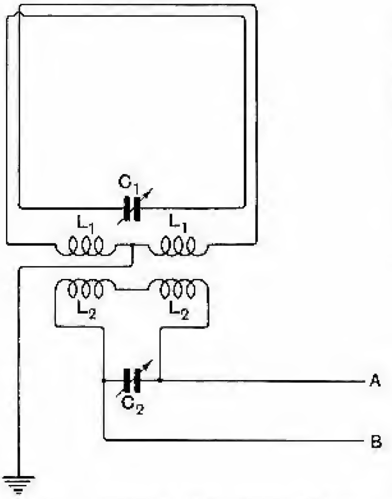


Fig. 74.—Earthed Mid-Point of Aerial Coupling Coils to Reduce Vertical.

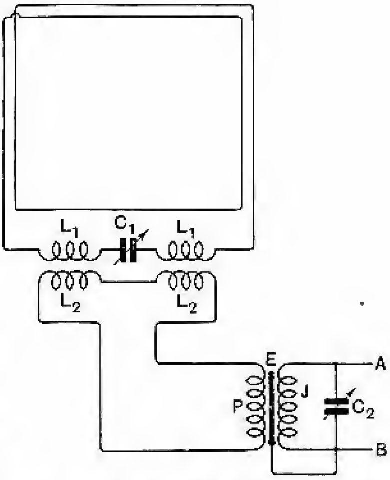


Fig. 75.—The Shielded Transformer Circuit for Reduction of Vertical.

Earthed Mid-Point of Frame Winding. Another, and very popular, method of retaining the symmetry or capacity balance of the frame to earth is by making an earth connection to the electrical centre of the frame winding, with appropriate alterations in the other circuit connections. This scheme will be found described on page 104, and is used in some of the commercial D.F.'s described on later pages.

The Shielded Transformer (Inter-Winding Shield). In Fig. 75 the aerial is tuned by the condenser C_1, connected between the two halves of the coupling coil L_1. L_2 is the secondary which is connected immediately to the primary winding P of a transformer, the secondary J being shunted by the condenser C_2. The transformer P J is very tightly coupled. Under these conditions the whole system, L_2 P J can be effectively tuned by means of the condenser C_2. This method of tuning is referred to in greater detail on page 117 in connection with the "Aperiodic Frame Aerial." Between the windings P and J, a copper foil shield E is interposed; this shield is metallically connected to the common negative terminal of the amplifier, which may be earthed.

Now, we have seen that in a circuit such as Fig. 70, vertical is largely due to electrostatic coupling between the aerial coil and the tuned grid coil. In Fig. 75 the presence of the shield E, which is maintained at zero—or practically zero—potential, provides an effective block against any such coupling, since an electrostatic field cannot pass through a conductor. This method of eliminating vertical is very effective.

Direct Reception or "Pick-Up"

The oscillatory circuits of any receiver consist of inductances shunted by condensers. These coils are really tiny aerials, and consequently will receive signals weakly, any such reception being quite independent of the frame aerial. The polar curve of the aerial will therefore be modified according to the intensity of the reception on the components and connecting wires comprising the receiving circuit. In the case of very small rotating frame aerials the "pick-up" may be quite comparable with the reception on the loop and large distortions will result.

The Effect of Pick-Up. As in the case of Antenna Effect, Pick-up results in an e.m.f. across the receiver input when the frame is in its normal position for cosine minimum and again results in indefinite and/or incorrect bearings, according to its phase relation to the main signal e.m.f.

Elimination of Circuit Pick-Up. In order to prevent direct reception on the coils of the receiver and amplifier it is necessary to enclose all the apparatus in earth-connected metal boxes, an electromagnetic wave being much attenuated in penetrating a conducting sheet. The boxes should be totally enclosed, as strong signals will act on a coil if the lid of a screening box be only slightly opened. In order to overcome the difficulty of adjusting apparatus which is boxed up in this manner, permanent stations which employed the small rotating frame as a direction finder or directional receiver have frequently been provided in the past with an operating room, built of copper or galvanized iron sheeting, the windows being covered with metal gauze.

Later it was found that individual units and components of directional receivers could be screened to almost any desired degree by means of the now familiar type of pressed metal cans and the use of screened operating rooms became unnecessary (2406).

Astatic Coils. An additional precaution often taken in directional receivers is to wind all coils in the receiving apparatus in sections and to arrange them astatically. Fig. 76 (*a*) shows an ordinary solenoid, with its distribution of flux, and such a coil is obviously susceptible to direct reception. If the coil be broken into two equal sections as in (*b*), which are then arranged as in (*c*), it will be seen that the magnetic circuit becomes closed, so that there is less magnetic flux outside the coil and, what is more important, the direction of the flux is up one coil and down the other. Any stray magnetic field will, therefore, have no effect on the combination, and coupling between adjacent coils in the receiver is also reduced.

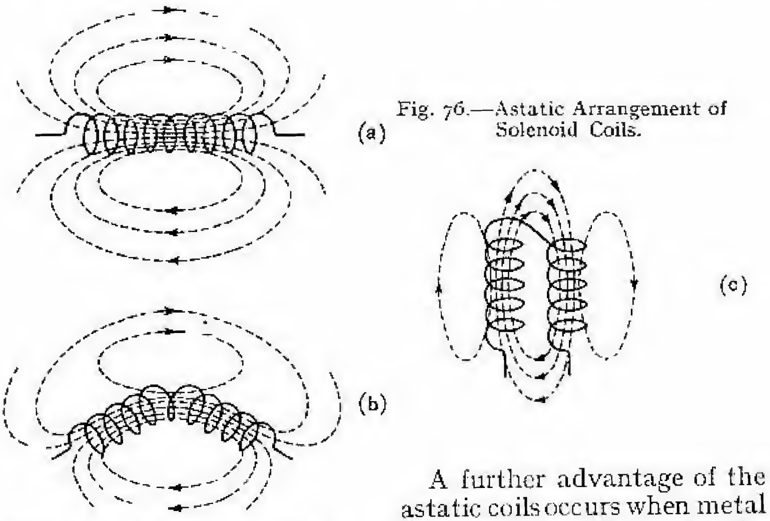


Fig. 76.—Astatic Arrangement of Solenoid Coils.

A further advantage of the astatic coils occurs when metal screening boxes are used for the apparatus. Owing to the concentration of the magnetic field inside the coils, a much smaller screening box can be used for a given amount of eddy current loss in the screen than in the case of the equivalent straight solenoid.

Dust Core Coils. The use of iron dust core coils and transformers for radio frequencies reduces the dimensions of the components, simplifies screening, and greatly reduces circuit pick-up.

Re-Radiation or Quadrature Effect

This effect comes into prominence chiefly in ship installations or in aircraft where a loop aerial—either of the rotating or the Bellini-Tosi type—has to be used in a position where it is near to metal work which itself is energized by the electromagnetic field.

In a ship there will be sections of the rigging, lengths of rail, ventilators, deck houses, funnels, masts or other objects which have natural periods of oscillation, and since the " tune " of the structures does not approach resonance with the received wave, the re-radiation will have a purely random phase with relation to the flux in the main wave.

As a result of this, there will be, near the loop, a field composed partly of the strong main field and partly of spurious waves arriving not only from wrong directions, but also with different phase relations, so that it will be impossible to get a pure zero with the cosine diagram.

It has been shown that this re-radiation may be split up into two components, so that the total effective field is made up as follows :

(1) The main wave, making an angle with the fore and aft line of the vessel which is the correct " relative bearing " (see page 583) of the distant transmitter.

(2) A component of the re-radiation which is also in phase with the main wave but making, with the direction of the main wave, an angle that depends on the relative positions of the surrounding metal masses of the ship.

(3) A component of the re-radiation that is in quadrature phase with the main wave and making, with the main wave, yet another angle depending on the disposition of the conductors producing the quadrature component.

Since the first and second of the components are in phase, they can be combined, giving finally two main component fields, thus :

(1) A field in phase with that of the wanted signal, but not necessarily arriving from the true direction.

(2) A field in quadrature phase and making, with the above field, an angle which depends on the relative positions of surrounding conductors.

These two components produce, of course, an elliptical field (page 22) the major axis of which will correspond with the main field and the minor axis with the quadrature field. If the latter effect is large and approaching the main field in intensity, the resultant will be almost circular and no bearings can be taken.

The general problem of the frame aerial acted upon by an elliptical field has been investigated by Mesny (2012), (2502), Heiligtag (2302), and Mainka (3711).

F. A. Fischer in a series of articles (2717), (2721), (2815), dealt in addition with the Telefunken Company's method of eliminating the quadrature component by means of an auxiliary aerial as described below, and C. E. Horton, in this country, has given a résumé of the subject in a valuable paper on the correction of errors in a ship D.F. installation (3104).

Elimination of Quadrature Effect. With regard to the task of taking bearings when the quadrature component is large, and the resultant field is almost circular, it will be clear that the condition is very much the same as that mentioned on page 21, but in that case the two component fields had horizontal and vertical electric force and rotated in a vertical plane. In this instance both fields are normally polarized, but are arriving from different horizontal directions, so that the resultant field is rotating in a horizontal plane and appears, to the Direction Finder, to have no defined bearing at all.

The solution consists in finding a site for the frame where the quadrature field is as small as possible and then neutralizing this remainder by the introduction of an e.m.f. from an auxiliary aerial, but a difficulty arises in that both minima of the cosine diagram cannot be sharpened by this means.

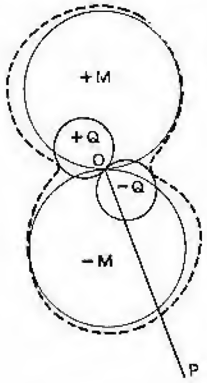


Fig. 77.—Polar Diagram of Main and Quadrature Fields in Ship D.F.

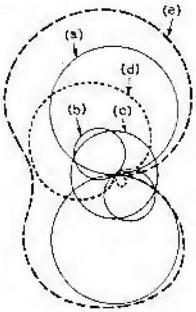


Fig. 78.—Polar Diagram as Fig. 77, with Addition of Circle Diagram in Correct Phase for Production of a Single Sharp Zero.

In Fig. 77, +M and −M represent the diagram due to the main field and +Q, −Q that due to the quadrature field. If along any direction OP we take the square root of the sum of the squares of the ordinates OM and OQ, the resultant gives a point on the received pattern which is shown by the dotted line. Now adding the circle diagram (*c*) in Fig. 78 of such amplitude and phase as to restore the sharpness of one of the MM minima, the result will not mean the suppression of the QQ diagram, but merely its conversion into an approximate cardioid (*d*) (similar to Fig. 54 (*b*) in this case), and the final diagram is (*e*) in Fig. 78. These drawings greatly exaggerate the effect but explain why it is usual to inspect only one of the cosine minima when using a **zero sharpening** device of this kind.

The sharp minimum can now be used to obtain bearings and the question of errors due to the distortion of the wave front of the main field is taken care of in the process of calibration of the D.F. under working conditions.

Vertical and Quadrature Effects. Some confusion very reasonably exists between these two causes of indefinite cosine minima since the symptoms are much alike and a balancing condenser circuit will often improve both. Actually they are quite distinct. Vertical or antenna effect is a circuit defect caused by capacity unbalance and results in equally bad minima in all directions and is capable of having both minima sharpened; or it may show up as comparatively sharp but displaced minima (i.e., not 180° apart). Quadrature is due to external causes, is usually worse in the thwartship direction than fore and aft in the case of a ship, and is capable of having only one minimum sharpened.

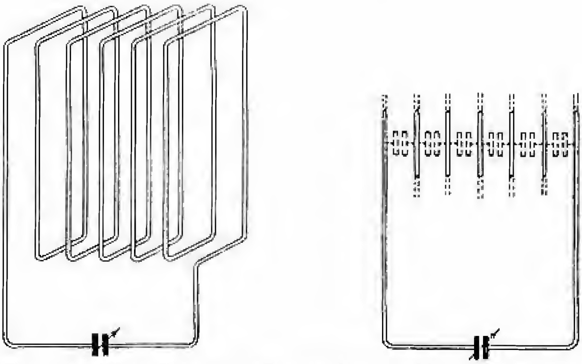


Fig. 79.—Displacement Current Effect in Solenoid Coil.

Displacement Current Effects

When a solenoid frame is placed in the theoretical position of zero reception, the vertical limbs of the successive turns are spaced in the direction of propagation of the wave and will, therefore, have e.m.f.'s of varying intensities induced in them. Between the successive turns there is also an appreciable capacity, and so a sort of phantom loop circuit is formed, which has its plane at right angles to the plane of the actual frame aerial as shown in Fig. 79.

When the aerial is in the plane of zero reception, this loop is clearly in the position of maximum reception, with the result that an e.m.f. is set up between the terminals of the frame which is in phase with the signal e.m.f. in the frame. Owing to the fact that this phantom loop is not tuned to the frequency of the incoming wave, the displacement current which flows will be approximately 90° out of phase with its e.m.f.

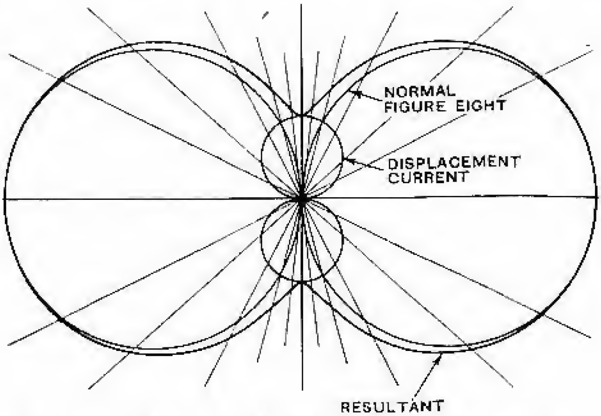


Fig. 80.—Distortion of Figure Eight Diagram due to Displacement Current Effect (Jour. Franklin Inst.).

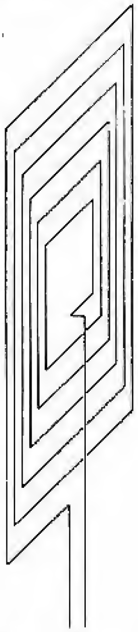


Fig. 81. — Pancake Form of Frame Aerial.

The displacement current effect changes sign when the coil is rotated through 180°; actually the change takes place at the instant of maximum reception by the frame, at which instant the displacement current is zero. Fig. 80 shows the polar curve of the normal frame reception, and also that of the displacement current effect, consisting of a smaller figure eight diagram at right angles to it. The resultant diagram is obtained by the vector sum of the two components, taking into account the fact that they are in quadrature.

With a pancake coil construction (Fig. 81), the Displacement Current effect is absent since, in the position of minimum reception, all the vertical limbs of the frame are in the same plane and parallel to the wave front. On the other hand, the pancake coil has a greater capacity to earth than the box form of coil of the same receiving power, and so is more prone to vertical. Multi-turn frames are sometimes constructed by a combination of the box and pancake forms, so arranged to have the minimum vertical and displacement current effects for a given value of area-turns.

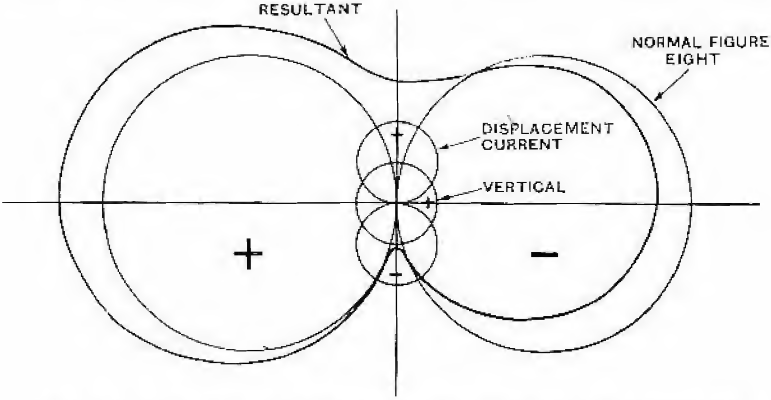


Fig. 82.—Distortion of Figure Eight Diagram due to Combination of Vertical and Displacement Current Effect (Jour. Franklin Inst.).

If a circuit has an appreciable degree of both displacement current and vertical, the effect is to make one minimum of the figure eight comparatively sharp whilst the other is extremely indefinite. Blatterman (1913) gives the resultant polar diagram of Fig. 82, by combining the three components with due regard to their phase relations.

FRAME AERIAL DESIGN

It is not proposed to consider the design of multi-turn frame aerials for long and medium waves; for details of this subject the reader is referred below to a number of papers and articles, in the reading of which, however, it is well to take careful note of how the various writers have obtained their results. As an example, suppose that a statement is made that a frame aerial of given dimensions, gauge of wire, number of turns and spacing has a certain optimum wave length when used for D.F. reception. It is first of all necessary to know whether the frame is to be connected to the amplifier by taking leads direct from the terminals of the frame tuning condenser as in Fig. 69, or whether it is to be inductively coupled as in Fig. 70. The results obtained will be different in the two cases and for the following reason.

If a frame aerial and tuning condenser could be represented accurately by the diagram of Fig. 83, then the problem would be a simple one for, in order to find the wave length which could be received with maximum signal strength, it would only be necessary to insert a current measuring device anywhere in the circuit and to note the wave length which gave maximum current—the field strength of the incoming wave being checked meantime to ensure that it was constant for all wave lengths and, of course, the frame being accurately tuned throughout. Alternatively, the potential difference across the tuning condenser could be measured and this would give identically the same result as the current measurement method since the whole of the current in the circuit is charging the condenser.

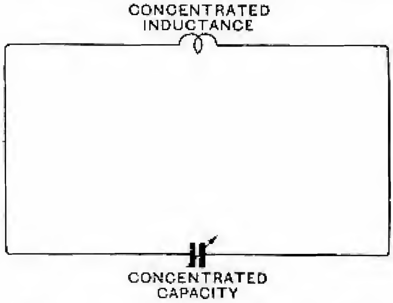


Fig. 83.—Schematic Drawing of Frame Aerial and Tuning Condenser.

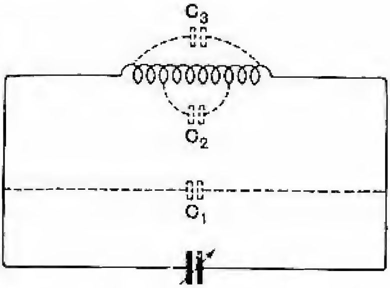


Fig. 84.—Frame Aerial and Tuning Condenser with Distributed Capacity Indicated.

We have seen, however, that the turns of a multi-turn frame have a considerable distributed capacity, so that the diagram of the circuit is more correctly indicated by Fig. 84, in which the capacity of the frame is shown by the small condensers C_1, C_2, C_3, etc. In this case it is clear that during the part of the oscillation, when the current is leaving the inductance to charge the tuning condenser, some of the current will flow into the distributed capacity of the windings and the condenser will not be charged to the same potential as it would if Fig. 83 represented the true state of affairs. If the wave length of the incoming wave be varied, it will probably be found that a condition of maximum condenser P.D. exists for some wave length other than that which gives maximum current in the frame and coupling coil.

Some writers on the subject of frame design tend to reduce the value of their work by not making quite clear how the measurements were made, and in other instances the measuring device appears to have been so located that the results are of very little use for any practical purpose.

In making use of frame design data the above points should be kept in mind, and provided that the conditions under which the tests were made are the same as those under which the frame is to operate, useful information can often be gained as to the dimensions to be adopted for a given wave range. On the other hand, the design of a frame is frequently governed by some other factor than maximum efficiency; the linear dimensions may be limited, the windings may be bunched together and enclosed—or partially enclosed—in wooden or metal weatherproof casing, connections may be made to other parts of the frame winding, in addition to the terminal connections, in order to suit some special receiving circuit, and so on. In any of these cases and many others the published design data would rarely be of any very great help, and the designer would make trials in order to find the best frame winding for the given conditions.

Of the many articles on medium- and long-wave frame aerials, the best known include those by Blatterman (1904 and 1913), Dellinger (1920 and 1922), Austin (2015), Mesny (2502) and also the following: (1911), (2210), (2220).

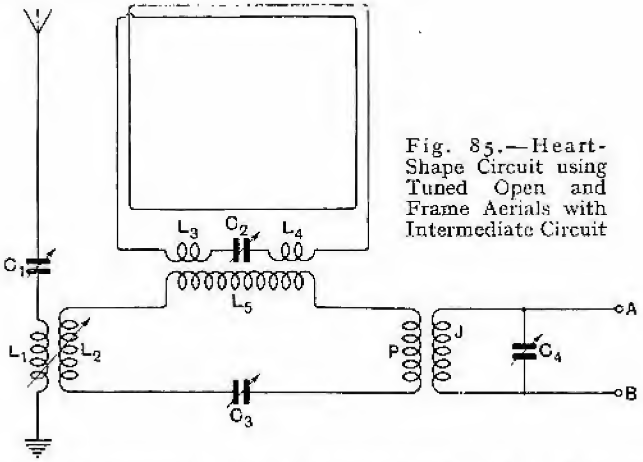


Fig. 85.—Heart-Shape Circuit using Tuned Open and Frame Aerials with Intermediate Circuit

DETERMINATION OF "SENSE" OR ABSOLUTE DIRECTION

The Heart-Shaped Diagram Circuit. It was shown on page 69 that the heart-shaped diagram of reception could be obtained by combining the effects of the frame and open aerials, and to do this the two aerial effects must be in the correct relative phase. It was seen, however, on page 56 that the e.m.f. induced in an open aerial by a passing wave is in phase with the flux in the wave, whereas, in the case of a loop aerial it was explained on page 62 that the e.m.f. is 90° out of phase with the flux in the wave. We cannot change the relative phases of these e.m.f.'s because they are inherent in the receiving properties of the frame and open aerials; we can, however, shift the phase of the current which flows as a result of an alternating e.m.f. by altering the reactance of the circuit, and in this way, the two currents in the open and loop aerials can be brought into step.

Fig. 85 illustrates a circuit which fulfils these conditions. The summation of the currents in the aerials is carried out in the intermediate circuit (L_2, L_5, $P\,C_3$) and their relative effects are controlled by the values of the couplings of this circuit to the two aerials. The necessary phase adjustments are obtained by the tuning condensers C_1 and C_2.

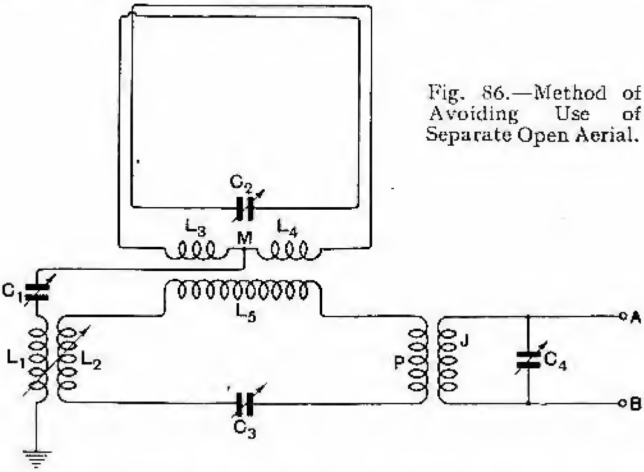


Fig. 86.—Method of Avoiding Use of Separate Open Aerial.

There is no necessity to use a separate length of wire for the open aerial. In Fig. 86 is shown a circuit in which the principle of earthing the mid-point of the coupling coils is used for this purpose. In Fig. 74, this was illustrated as a method of reducing the effect of vertical, but here the vertical is actually used to supply the required open aerial e.m.f. The incoming wave will induce an e.m.f. between the frame aerial, taken as a whole, and earth and this e.m.f. will cause an alternating current to flow from the mid-point M to earth through the condenser C_1 and the coil L_1. Half this current in the frame aerial will flow through L_3 and half through L_4 since the aerial is symmetrical in every way. These two currents being in opposite directions through L_3 and L_4 there will be no resultant magnetic field produced in L_5 and the amplitude of the e.m.f. induced in the intermediate circuit may be controlled entirely by the coupling between L_1 and L_2 and the phasing by C_1 and C_2, as before.

Phase Adjustment of Heart-Shape with Tuned Aerials. We know that reducing either the inductance or the capacity in a simple open aerial circuit has the effect of increasing the ratio of capacity reactance to inductive reactance and produces a " leading " current. On the other hand an increase in the " tune " of the circuit decreases this ratio, and results in a " lagging " current.

Consider now the adjustment of the circuit of Fig. 86 with the aid of a vector diagram showing the phase relations of the e.m.f.'s and currents in the two aerials. In Fig. 87, OF is the vector representing the flux in the wave, E_v is the e.m.f. in the open aerial which we know to be in phase with the flux in the wave (page 55) and E_f is the frame aerial e.m.f. which lags 90° on the flux. (Assuming counter-clockwise rotation of vectors.) Now suppose we adjust C_1, Fig. 86, so that the current in the open aerial leads 45° on the e.m.f. as illustrated in Fig. 87 (*a*) by the vector I_v. Further, C_2 is adjusted so that the frame current *lags* 45° on the e.m.f. in the frame, this being shown by the vector I_f which is seen to be in phase opposition to I_v. By means of the couplings between the two aerials and the intermediate circuit, these two currents can be arranged to induce e.m.f.'s, in the intermediate circuit, which are equal in amplitude and in opposite directions round the circuit, giving the condition of zero signals which is taken to indicate sense when using the heart-shape circuit.

Reversal of Sense. Two possibilities are described below whereby an incorrect sense indication may be given owing to mistakes in the adjustment of the circuit, and a third is mentioned on page 122.

Reversal of a Coupling. Suppose that when the circuit is correctly balanced, the coupling L_5 be reversed, either by changing the connections over or by actually turning the coil round. This process means that we reverse, at every instant, the direction of the e.m.f. induced in the intermediate circuit by the frame aerial and this corresponds to a 180° change of phase. In this case, instead of the diagram of Fig. 87 (*a*) we get that of Fig. 87 (*b*), where I_f is now in phase with I_v so that the heart-shape maximum is obtained. In order to get a zero balance, without further alteration to the circuit, the frame aerial will have to be rotated through 180°, which is the equivalent of a reversal of sense.

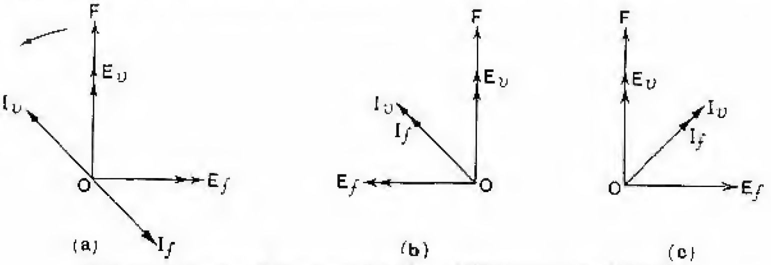


Fig. 87.—Vector Diagrams for Tuned Heart-Shape Circuit.

Incorrect Phasing. Suppose that having adjusted the phase of the open aerial so that the current leads 45° and that of the frame aerial so that the frame current lags 45° it is found that a correct sense indication is given. Now imagine these phase relations to be reversed by slight mistuning, so that the open aerial current *lags* 45° and that of the frame *leads* 45°, then, as shown in the vector diagram of Fig. 87 (*c*), I_v and I_f are again in phase and, just as in the above case a reversal of sense again occurs.

The danger of a reversed sense indication and the combination of difficulties attached to the operation of the heart-shape circuit with tuned aerials led to the development of a method of phasing which gives far more stable conditions.

APERIODIC OR "RESISTANCE PHASED" OPEN AERIAL

On page 57 was given an example of the effect upon the impedance of an aerial caused by a comparatively small amount of detuning of the circuit and it was seen that the amplitude of the aerial current changed far more rapidly, for a given degree of mistuning, when the aerial resistance was low. The effect upon the phase relation of the current and e.m.f. is equally striking.

The aerial in the example had the following constants:

Resistance, 10 ohms.
Total Inductance, 202·64 μhy.
Total Capacity, 0·0005 μfd.

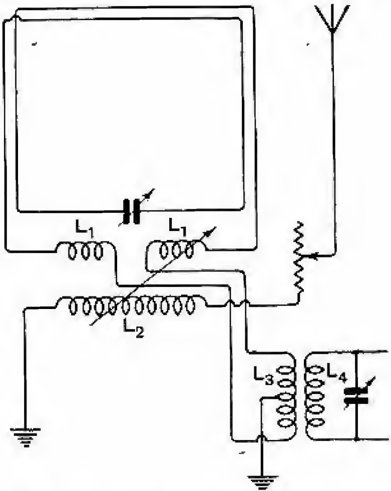


Fig. 88.—Heart-Shape Circuit using Tuned Frame and Resistance Phased Open Aerial.

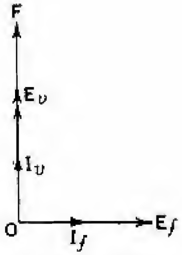


Fig. 89. — Vector Diagram for Circuit of Fig. 88.

giving inductive and capacity reactances of 636·6 ohms at an applied frequency of 500,000 corresponding to a 600 metre wave length. When detuned by means of the variable condenser so that the capacity was 0·00049 μfd., the capacity reactance became 649·6 ohms.

If ϕ be the angle of lead, then :

$$\text{Tan } \phi = \frac{649{\cdot}6 - 636{\cdot}6}{10} = 1{\cdot}3 \text{ and } \phi = 52^\circ\ 25'.$$

The 2% change in capacity, which is equivalent to a $8\frac{1}{2}$ m. change in the natural wave length of the circuit, has thus produced a 52° angle of lead in the aerial current.

Suppose now that the aerial resistance be increased to 100 ohms, then, $\tan \phi = 0{\cdot}13$ and ϕ is reduced to $7^\circ\ 25'$. With an increase of aerial resistance to 1,000 ohms, $\tan \phi$ becomes 0·013 and ϕ is only $0^\circ\ 45'$ so that provided that resistances of this order can be tolerated, there exists a method of stabilising the phase relation of the aerial current and e.m.f., even though the periodicity of the circuit, or conversely, the applied frequency, may vary several per cent. But we know that the e.m.f. round a frame is very small compared to that in an open aerial of the same height, and it is found that resistances up to 2,000, 3,000 or 5,000 ohms can be put in series with an open aerial of moderate size, and, by coupling to a frame aerial as in Fig. 88, an e.m.f. can be induced which will balance that induced directly in the frame by the wave.

There is an important difference between the circuit of Fig. 86 and that of Fig. 88 in that there is no common intermediate circuit used in the latter and also the frame in Fig. 88 is tuned exactly to the incoming wave instead of being slightly mistuned in order to give the necessary 45° lead or lag to the frame current. The vector diagram for the condition of heart-shape balance is given in Fig. 89 where OF is the flux in the wave and E_v the open aerial e.m.f. in phase with the flux. I_v is also in phase with E_v because the added resistance in the open aerial swamps the effect of any slight mistuning which may exist. The frame e.m.f. lags 90° on the flux in the wave and since the frame is accurately tuned, the current is in phase with the e.m.f. and is also 90° out of phase with I_v. The e.m.f. induced in L_1 by I_v will, however, lag 90° on the current I_v so that provided the coupling between L_1 and L_2 has been adjusted to give the correct amplitude, there will be an exact balance. Mistuning of the frame will not appreciably affect the minimum of the heart-shaped diagram and can never result in a reversed sense indication.

Valve-Coupled Open Aerial. A method of rendering an open aerial almost completely aperiodic is shown in Fig. 90. The open aerial is connected to earth through a resistance of about 100,000 ohms, the top point of which is connected to the grid of a valve; the values of plate current and grid bias being so arranged that the valve is working on the straight part of its I_a V_g characteristic and is not passing grid current at any time. The anode circuit of the valve contains the coupling coil to the frame or the low damped intermediate circuit of a directional receiver.

This arrangement is almost aperiodic and all oscillations taking place in the open aerial will cause corresponding fluctuations in the potential of the grid of the valve, due to the

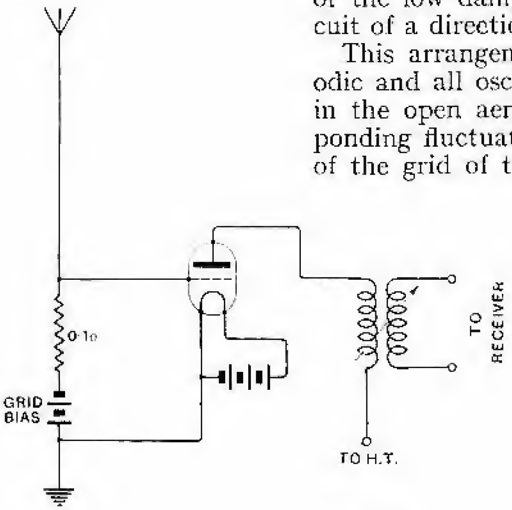


Fig. 90.—Valve-Coupled Aperiodic Open Aerial.

varying potential drop across the resistance. These oscillations will be repeated in the anode circuit and the coupled circuit will respond to that frequency to which it has been tuned, so that, by adjusting the coupling between them, a correct cardioid balance can be got with very little trouble.

This method of coupling the open aerial to the receiver has the advantage that in case the ratio of open aerial reception to frame reception in any installation is not high enough to give a satisfactory heart-shaped diagram, after the requisite amount of resistance has been added for phasing purposes, the amplification of the valve will bring the open aerial effect up to the required amount.

The simple circuit described above has to be slightly modified in practice. Owing to the very high resistance of the open aerial, any charge imparted to the aerial will take an appreciable time to leak away, and during a storm of rain from an electrically charged cloud, a large positive or negative charge will collect on the aerial and will have the effect of sweeping the coupling valve either up its curve to saturation or down to zero plate current. The circuit is therefore more usually arranged as in Fig. 91, which provides capacity coupling from the aerial to the valve, allowing the grid to follow the fluctuations in potential across the aerial resistance without being affected by a static charge.

Cross Modulation with the Valve-Coupled Open Aerial. Unfortunately, this use of a coupling valve is subject to cross-modulation. Suppose that the frequency which it is desired to receive is, say, 100 kc. and that there are two transmitters in the neighbourhood working on frequencies of 1,000 and 900 kc. respectively. The difference in frequency between the two transmitters is 100 kc., but this should have no jamming effect since the beat frequency is not rectified and therefore there is no component at the 100 kc. frequency. If, however, the coupling valve rectifies this 100 kc. beat in the slightest degree, then there will be interference whenever the two stations are both radiating, and the result is a disconcerting form of jamming in which a receiver tuned to a medium wave length can be jammed by transmitters in the short wave band.

Reduction of Cross Modulation. Theoretically the valve is working on the straight part of its I_a V_g curve, but no valve has a perfectly straight characteristic and a slight amount of rectification always takes place. The effect can sometimes be reduced by the use of a higher plate voltage, but there is another method which is applicable to the valve coupling of aerials, and which has been very successfully used in D.F. work.

Negative Feed Back. Fig. 92 shows a valve circuit in which Z is the anode load and there is a resistance R in the cathode circuit, thus giving "automatic" bias. The input is across AB. The resistance R is not shunted by a condenser, so that the bias on the grid is a function of the instantaneous anode current, and a form of negative feed back is produced which has an interesting effect upon the valve characteristic. The effect was first investigated by H. S. Black, but has more recently been dealt with by H. Bartels (3417), who has devised a simple graphical method of showing the modification to the valve performance.

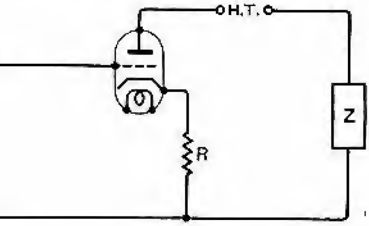


Fig. 92.—Negative Feed-Back in Open Aerial Coupling Valve for Reduction of Cross Modulation.

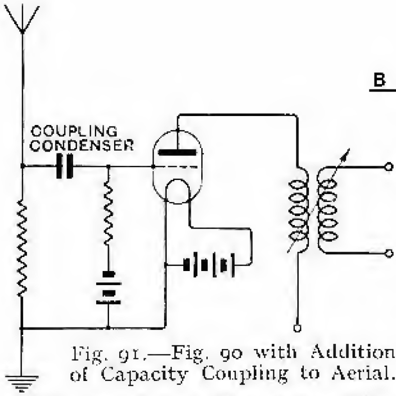


Fig. 91.—Fig. 90 with Addition of Capacity Coupling to Aerial.

Fig. 93 shows the normal E_a—I_a curves for an ML4 valve shown in the full lines, together with the 5 watt dissipation curve. Now, suppose that the valve be used as in Fig. 92, with a 400 ohm cathode resistance. In this case, with say zero steady grid bias and 10 m.a. anode current flowing, the actual bias on the grid will be 10 × 400 millivolts or —4 volts, and instead of the operating point being at A, it will be at B. Similarly, with 20 m.a. flowing, the feed-back bias will be increased to —8 volts and instead of operating at E, the conditions will be those at F, and so on.

Again, if the steady grid bias be —4 volts, then with 10 m.a. anode current, there will be an additional feed back bias of —4 volts, and the operating point will be transferred from B to C.

It is thus seen that the new E_a I_a curves, shown dotted, whilst starting from the same origins, are all sloped over to the right, and are made appreciably more straight in the process. This reduction in slope results in a reduced gain, but the important point is that the distortion components arising from the valve curvature are found to be reduced at a greater rate than is the magnification of the fundamental frequency. This can be confirmed by plotting a load curve in the usual way and noting the small harmonic distortion.

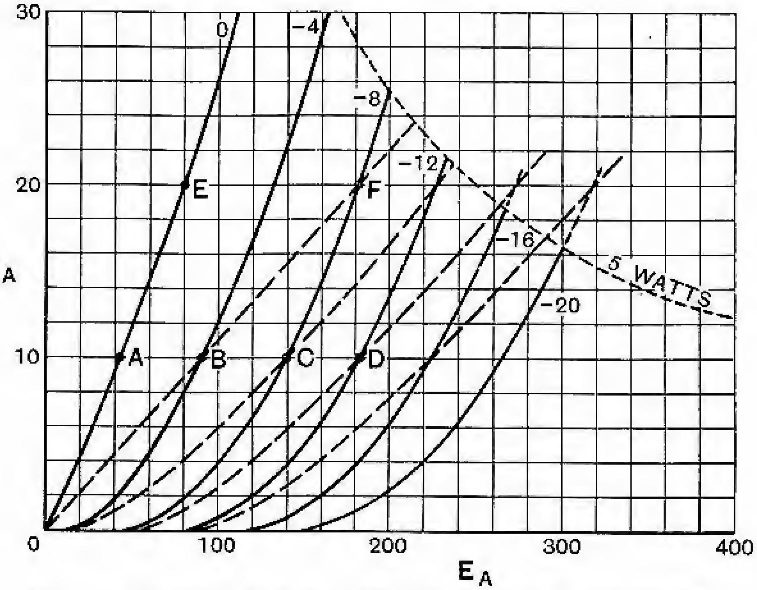


Fig. 93.—Graphical Method of Showing Increase in Linearity of I_a—E_a Curves of Valve in Fig. 92.

An ML4 valve has been chosen as an illustration because it shows more clearly the effect of the feed-back circuit, but in practice a valve with less curvature would be selected for the purpose.

THE ROTATING FRAME AERIAL WITH MID-POINT EARTH CONNECTION

The frame connection described in the following pages is less conventional than the straightforward circuit dealt with up to the present but has, amongst its other virtues, a marked freedom from vertical effect. It is also claimed to have greater stability, to require a balancing condenser of smaller capacity owing to its increased symmetry, and to increase the frequency range of a given frame, by a small amount, owing to the removal of the valve capacity from across the frame tuning condenser terminals (2703).

The popularity of the circuit may be judged from the fact that in various modified forms it has been used by many of the principal designers or manufacturers of rotating frame D.F. apparatus.

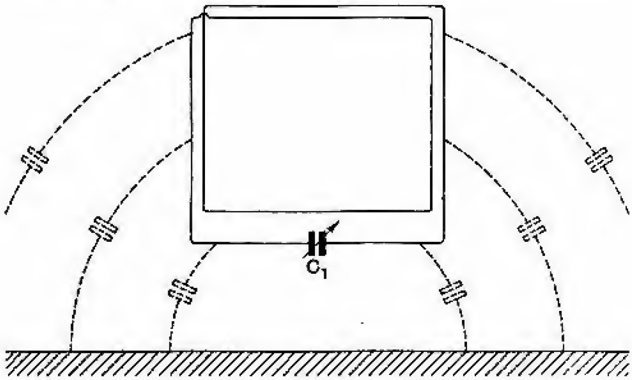


Fig. 94.—Capacity to Earth of Frame Aerial.

In Fig. 94 is shown a frame aerial which may be assumed to be situated a few feet above the earth and tuned to an incident wave by the condenser C_1. This frame has a capacity to earth as illustrated by the dotted condensers, and clearly there must be some point E at, or near, the mid-point of the frame winding which can be connected directly to earth as in Fig. 95 without disturbing the symmetry of the circuit. The changes of potential across the plates of C_1 still remain of the same amplitude as before and any vertical effect which was present due to the frame functioning as an open aerial, has been fairly effectively neutralised.

Now let one plate of the condenser C_1 be connected to the grid of the first valve of the amplifier as in Fig. 96. In order to retain the symmetry of the circuit, the " mid-point " connection will have to be moved from E to some point E_1 in order to make up for the added filament-grid capacity of the valve; it being assumed that the common negative pole of the amplifier batteries is also connected to earth. This arrangement is found to give a very good figure eight diagram with crisp minima free from the effect of vertical.

In practice where the frame connections are taken down a metal shaft, as in ship installations, to a receiver below, the position of the earth connection is found to be less critical.

The Balancing Condenser. In Fig. 97 is shown the application of the differential balancing condenser which, as in the case of that shown in Fig. 72, probably performs the double function of a fine adjustment on the capacity balance and also of a quadrature effect zero cleaner.

Unilateral Reception. Vertical effect is normally prevented in the circuit of Fig. 96 by the direct earth connection of the electrical centre of the frame, which virtually short-circuits the open aerial to earth and prevents it from ever assuming an appreciable potential above that of the earth. If now this direct earth connection be modified by introducing a variable resistance, as in Fig. 98, the vertical effect will gradually become more noticeable as the resistance is increased and the short-circuit removed, for there will now be a definite potential drop across the resistance R. The potential changes of the point E_1 will be communicated to both plates of C_1 and, being independent of the direction of the incoming wave, will produce a circle diagram of reception, the amplitude of which can be varied by means of the resistance R.

By suitably adjusting the relative amplitudes of the circle and figure eight diagrams, a resultant diagram can be obtained which will indicate sense although a true cardioid is not possible with this simple circuit. As there is no tuning condenser or inductance in the "open aerial" circuit, the phase of the current due to vertical effect will lead by a large angle on the open aerial e.m.f. and since the frame current is assumed to be in phase with

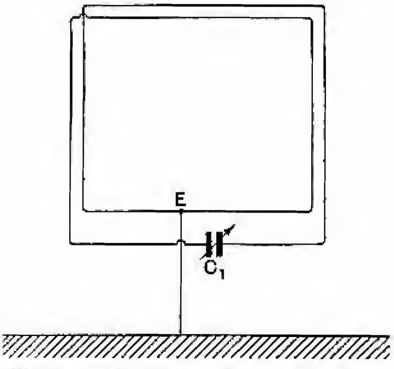


Fig. 95.—Symmetrical Earth Connection of Mid-Point of Frame.

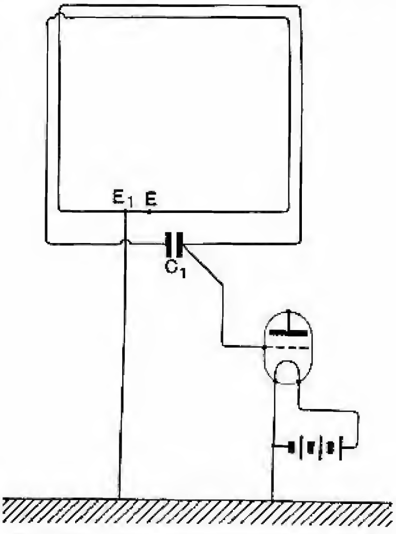


Fig. 96.—Asymmetry of Frame due to Grid Connection.

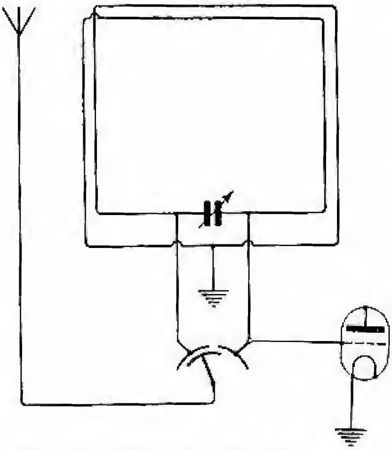


Fig. 97.—Balancing Condenser for Restoring Symmetry of Circuit.

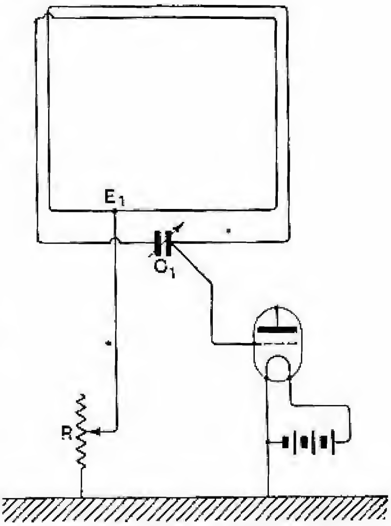


Fig. 98.—Resistance R inserted to Increase Vertical Effect and give Unilateral Reception.

its e.m.f., a diagram with a sharp minimum will not be possible unless the frame be slightly detuned.

In Fig. 99 is shown a modification of Fig. 98, which allows of a perfect cardioid diagram being obtained. The behaviour of the circuit will be more clear if it be redrawn as in Fig. 100 where FF are the two halves of the frame. This will be seen to be exactly the same circuit, but the action of the vertical effect is easier to follow. The system has two degrees of freedom. The frame effect is due to the e.m.f. induced round the frame, the complete frame circuit now consisting of the active section FF and also the two coils L_1 L_2 which are in parallel with the frame across the condenser C_1. Acting as an open aerial, the complete system is tuned by the condenser C_2 and with this arrangement, the phase of the vertical current can be made to balance the frame current and the relative amplitudes varied as before by the resistance R.

Frame Aerial Reaction. The use of valve reaction on a frame aerial used for direction finding is generally attended by indefinite minima owing to the fact that the troubles due to lack of symmetry of the circuit are exaggerated. Fig. 101 shows a way in which the above circuit may be adapted to the use of reaction by employing a separate reaction valve, the grid of which is connected to the plate of the tuning condenser C_1 other than that to which the amplifier is connected. The anode coil of the reaction valve is coupled to L_1 L_2, the mid-point of which is maintained at earth potential, thus ensuring that there shall be no capacity coupling. An alternative method is shown in Fig. 102.

Reaction Using Condenser Control. Fig. 103 shows a similar arrangement in which a differential condenser is used for coupling between the grid circuit of the first valve and the plate circuit of either the first or second valve by means of which any degree of reaction or anti-reaction may be applied.

Zero-cleaning is obtained by using a three-plate condenser, the stators of which are connected across the frame tuning condenser and the movable vane to the open aerial. This arrangement cannot be used for obtaining a cardioid.

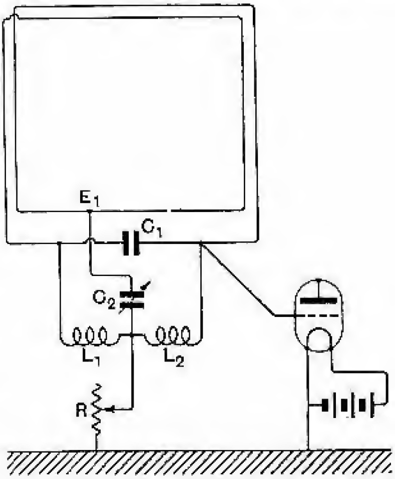


Fig. 99.—Modification of Fig. 98 to give True Heart-Shape.

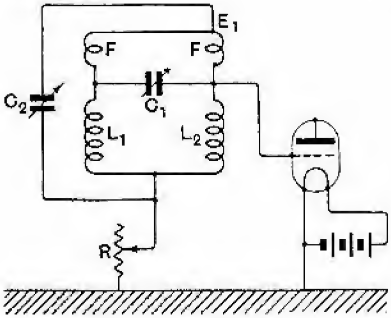


Fig. 100.—Re-arrangement of Fig. 99 to illustrate the Two Degrees of Freedom of the Circuit.

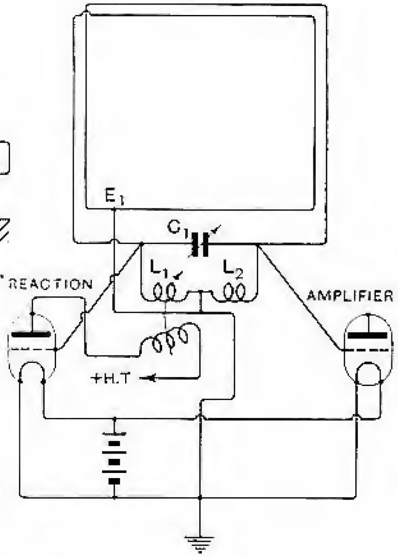


Fig. 101.—Frame Reaction by Use of Second Valve.

Frame Reaction and Sense Determination. Fig. 104 differs from the previous one in having a coupling coil at the centre of the frame, the mid-point of which coil is taken to a potentiometer connection across the filament batteries for the purpose of applying the correct potential to the grid of the first H.F. valve. The open aerial, which is tuned for the purpose of sense determination, is fitted with a switch which cuts out the tuning condenser so that the aerial may be used for zero cleaning.

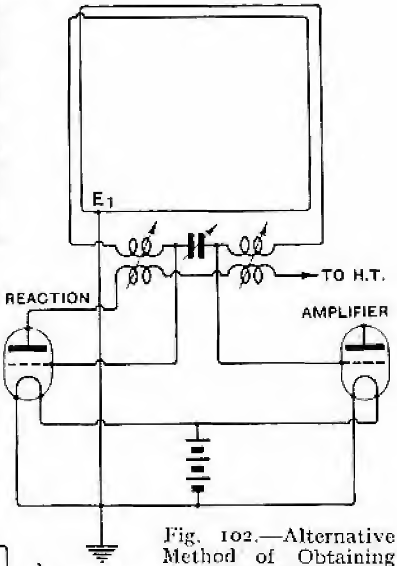


Fig. 102.—Alternative Method of Obtaining Frame Reaction.

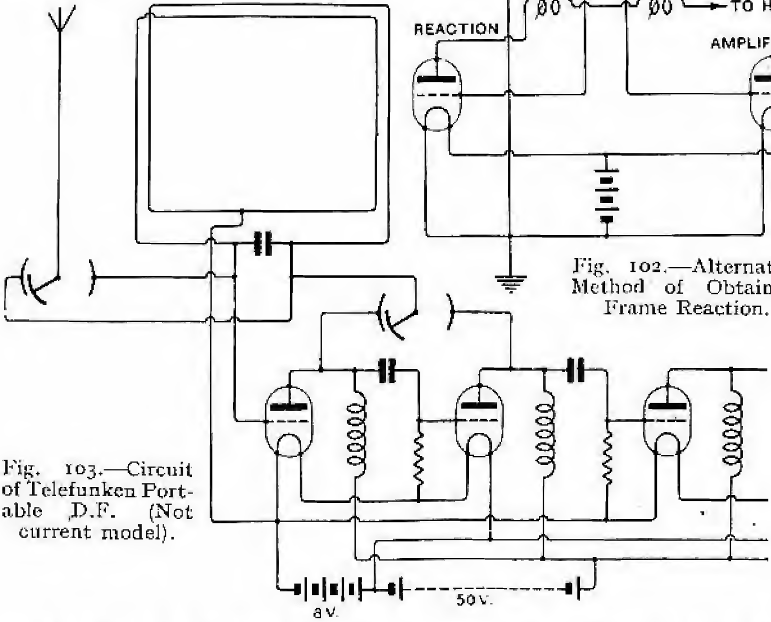


Fig. 103.—Circuit of Telefunken Portable D.F. (Not current model).

EXAMPLES OF DIRECTION FINDERS USING THE EARTHED MID-POINT FRAME CONNECTION*

Type ER-1445-C D.F. of the Radiomarine Corporation of America. This apparatus employs a tuned rotating loop with metallic screening of the type shown in Chapter 11. The diagram of Fig. 105 shows that the centre of the loop is earthed, the extremities of the loop being connected to the tuning condenser, one side of which goes to the grid of the first H.F. pentode amplifier valve. The frame is thus connected as in Fig. 96.

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* The simplified circuit diagrams described here and later in this chapter refer in some cases to apparatus mentioned in more detail in the installation chapters. They are introduced at this point as examples of the principles discussed in the text and to reduce the necessity for vector diagrams, etc., in the later sections of the book.

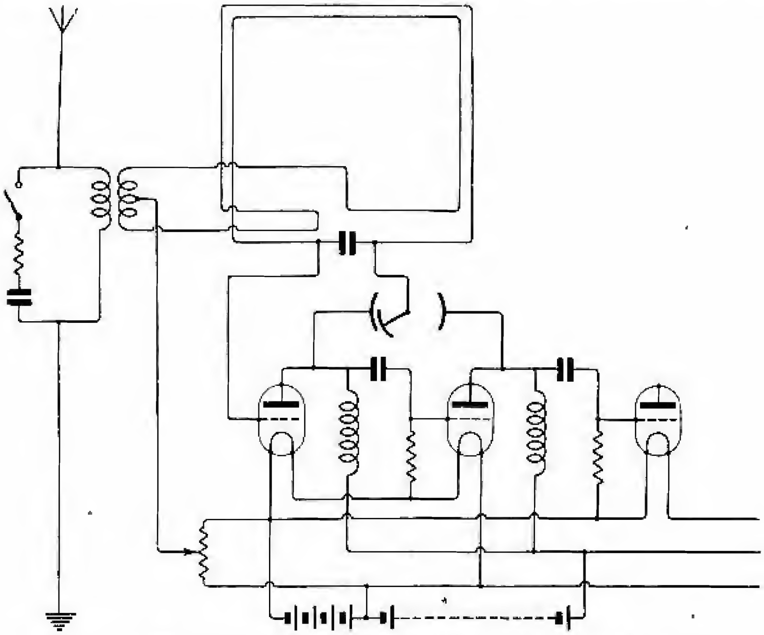

Fig. 104.—Circuit of Telefunken Ship D.F. (Not current model.)

In the frame circuit are the loading coils L_7, and the coupling coils L_2 L_3 forming part of a screened balancing assembly. L_4 couples the open aerial via either the loading coil L_5 for balancing (or zero sharpening) or via R_1 for sense determination. The open aerial is tuned by the ganged condenser C_5 and the variometer L_6.

These variable condenser and inductive loadings are pre-set to give the correct phasing for zero cleaning and uni-lateral reception over the tuning range of the receiver which is from 270 to 550 kc. (1,110 to 545 m.).

Further details of the apparatus will be found on page 452.

A Bureau of Standards (U.S.A.) Portable D.F. The circuit of a portable D.F. with a wave range of 39 to 3,330 m. (7,692 to 90 kc.) and having only two adjustments, namely for tuning and balancing, is shown in Fig. 106. Although this instrument was developed about 1926 it is included as an example of the difficulties involved in employing a super-

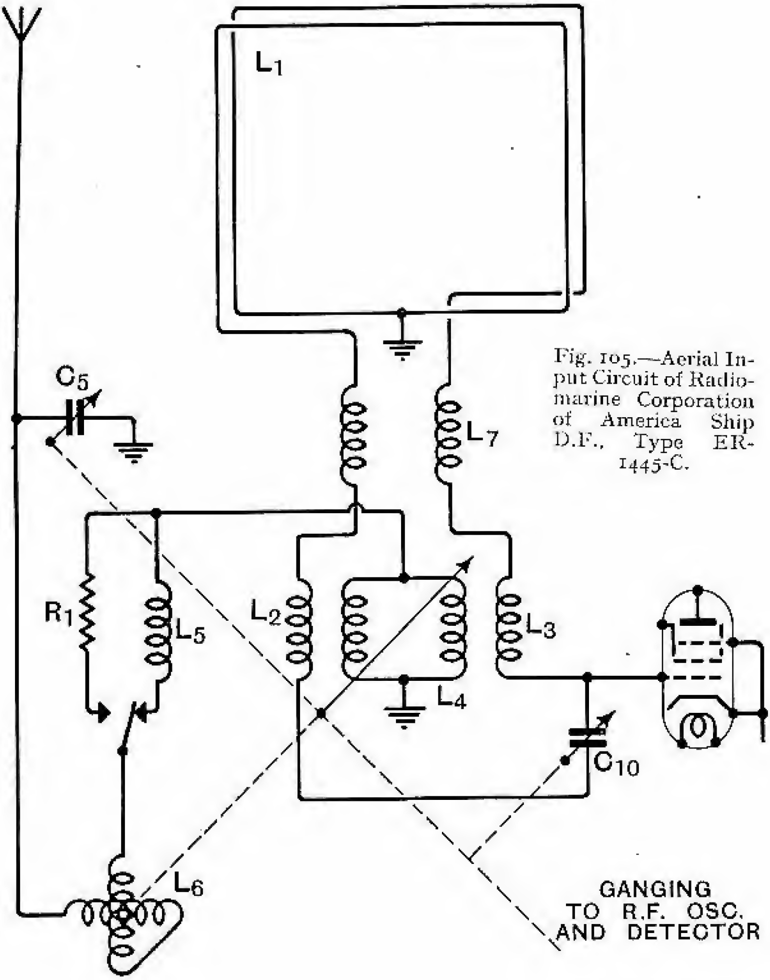

Fig. 105.—Aerial Input Circuit of Radiomarine Corporation of America Ship D.F., Type ER-1445-C.

heterodyne receiver for a D.F., when it is desired to reduce the controls to such a small number (2703).

The frame J is tuned by the condenser A, one of the leads

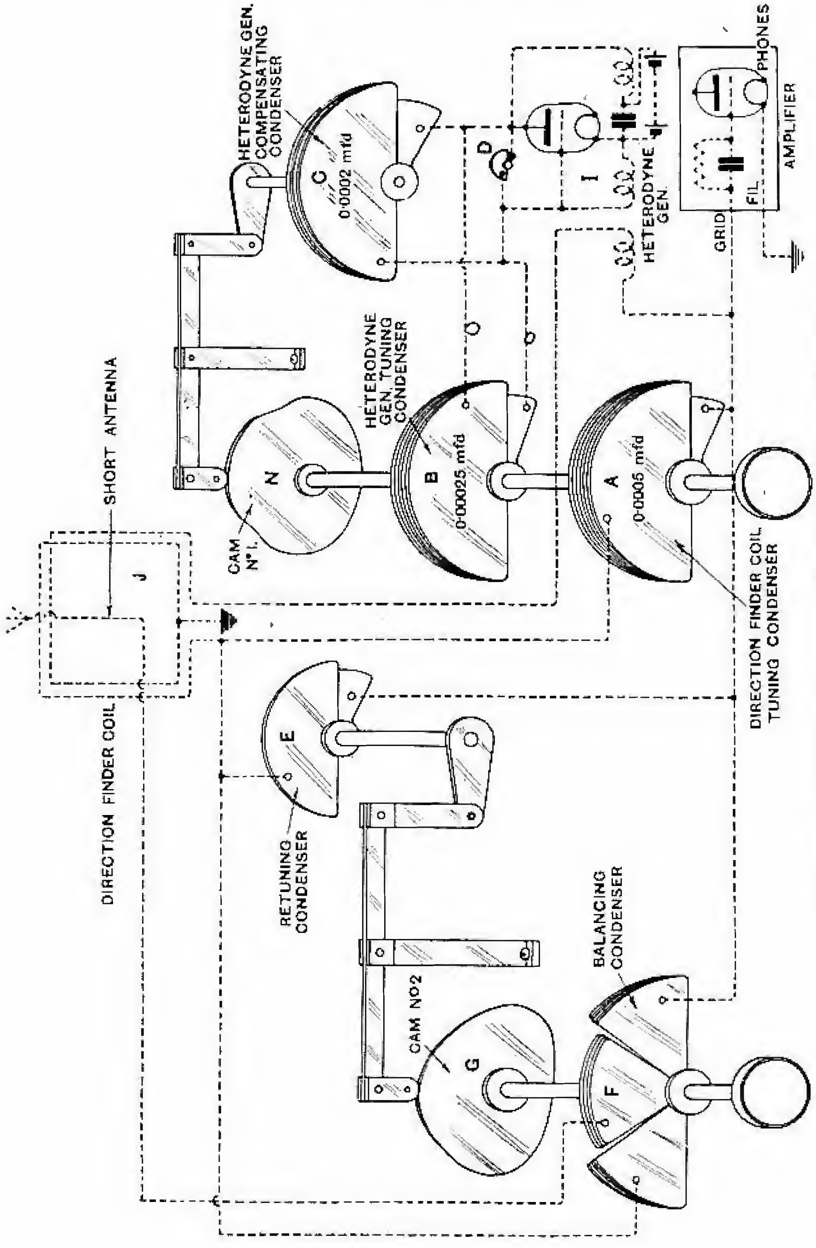

Fig. 106.—Circuit of a Bureau of Standards Portable D.F.

to which includes a winding of a transformer I which couples the frame to the heterodyne. The moving plates of the main tuning condenser B of the heterodyne are on the same spindle as those of the frame tuning condenser, and this spindle also carries a cam (No. 1) which controls a heterodyne compensating condenser C. The function of this latter condenser, which is in parallel with B, is to maintain a constant 66·67 kc. intermediate frequency beat with the incoming wave, over the whole tuning range.

The wave range is obtained by the use of seven sets of frames, heterodyne coupling coils, heterodyne tuning coils, cams and scales for the unicontrol tuning scheme. The scales are calibrated in kilo-cycles and enable the D.F. to be tuned rapidly.

The three-plate balancing condenser F, the moving vane of which is connected to the open aerial, controls by means of a second cam (No. 2) a condenser E which is in parallel with the frame tuning condenser A and compensates for the detuning effect of the balancing condenser. It was found that on low wave lengths it was necessary, without this compensating condenser, to retune after balancing.

It will be noticed that the centre point of the frame and also the filament battery are connected to earth and that the grid and filament of the H.F. amplifier are thus only connected across half of the frame, the other terminal of the frame being taken to the balancing condenser.

THE ROBINSON D.F. SYSTEM

Later in the book it will be found that in certain forms of aircraft directive reception, two equal strength signals are balanced against one another to indicate the required direction, instead of working on a zero signal as is the case with a cosine minimum.

This may be desirable due to ignition induction or because the signal must be read throughout the D.F. operation, which is impossible if it passes through a zero value.

The above defect was obviated in the Robinson system in which the bearing of a station is indicated by a minimum value of signal strength, but this minimum is not a zero point. The method consists essentially in the use of two frame aerials fixed at right angles to one another, and free to rotate about a vertical axis. One of these frames (Fig. 107) is known as the Main Coil and, at the instant of taking the bearing, this frame is in the plane of the direction of the incoming signal ;

that is to say, the induced e.m.f. is a maximum. The second frame is called the Auxiliary Coil and has no e.m.f. induced in it under the above circumstances. If, therefore, switching arrangements be provided whereby the auxiliary coil may be placed in series with the main coil, first in one direction and then the other, no appreciable difference should be observed in the resultant e.m.f. of the two frames from that induced in the main coil alone. The aerial system is tuned by means of the variable condenser and the signals are amplified and received in telephones in the ordinary way.

Fig. 107 shows the circuit in which S_1 is arranged to reverse the auxiliary coil when it is in series with the main coil and the switch S_2 disconnects the auxiliary coil and replaces it by a balancing inductance L, which is given such a value that the circuit is not thrown out of tune when receiving on the main coil alone. A transformer is inserted in the leads to the amplifier which prevents the grid of the first valve of the amplifier being isolated during switching operations.

Fig. 108 shows plan views of the two frames at right angles together with the polar diagrams of reception of each. If now, the direction of the incident wave corresponds exactly with the maximum of the main coil, then the e.m.f. induced in the main coil will be proportional to the ordinate Om and there will be no e.m.f. in the auxiliary frame. Suppose, on the other hand, the direction of incidence of the wave makes a small angle θ with the plane of the main coil, then the e.m.f. in the main coil will be Om′, which is practically equal to Om, and the e.m.f. in the auxiliary frame will be Oa′. On alternately adding or subtracting the e.m.f.'s in the two coils, the resultant will vary from Or′ to Or, the difference being equal to twice the e.m.f. in the auxiliary coil and the sensitiveness of the method depends on what is the smallest ratio of Or′ : Or which can be detected by the human ear. Clearly, the directive properties are vested in the auxiliary coil and the greater the receiving power of this coil is made relative to the main coil, the greater will be the ratio of Or′ : Or for a given angle θ.

If the polar diagrams of the two frames be combined for each position of the reversing switch, it will be found that the effect of connecting the coils in series, first in one sense and then in the other, is virtually that of swinging a single coil, of rather greater dimensions, through a small angle, as shown in Fig. 394.

Errors. The direct reception on the main coil connections, or transformer primary, which is in phase with the signal e.m.f. serves only to increase the main coil maximum signal intensity and does not affect the accuracy of the bearings. Direct reception on the auxiliary coil leads will produce errors since, even when the coil is at right angles to the direction of the incident waves, there will be a residual e.m.f. across the reversing switch terminals.

Vertical gives blunt minima when out of phase with the signal e.m.f.; if in phase, it results in the auxiliary coil minima being less than 180° apart, with consequent error.

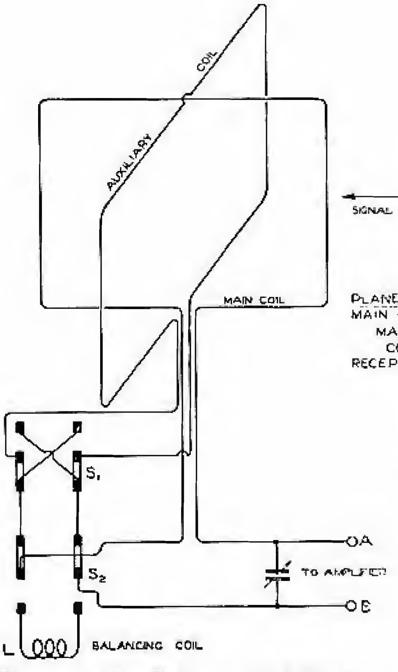

Fig. 107.—The Robinson D.F. Circuit.

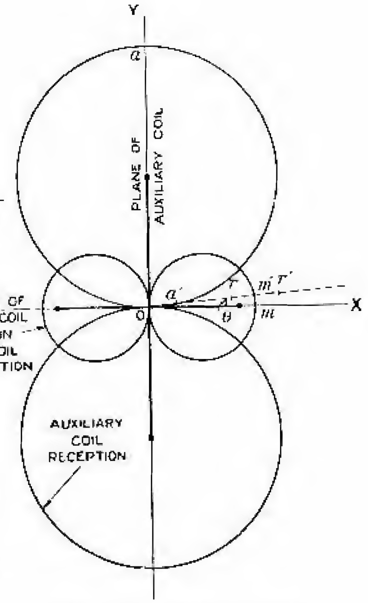

Fig. 108.—Theory of the Robinson D.F.

Direction Finding with the Robinson System. The unequal receiving powers of the two coils, whilst improving the sensitiveness of the apparatus, may lead to difficulty in its operation owing to a certain ambiguity which may possibly arise. The original method of taking a bearing was to obtain approximately maximum signals on the main coil, with the balancing coil in series, and then to throw the switch S_2 (Fig. 107) and find the exact maximum point by means of the reversing switch S_1, in the manner described above. Since some difficulty is always met in finding the position of the maximum signal strength on the main coil, it may happen that when the auxiliary coil is switched in, the methods of balancing mentioned above do not give the desired result.

Fig. 109 shows the two equivalent simple frame polar diagrams superimposed, the direction of balance being along XO, in which case the signal strength for both positions of the reversing switch is Or. Suppose, however, that for some reason, the frames have been rotated until the direction of the incident wave is along the line PO, then on switching in the auxiliary coil and operating the reversing switch, the signal intensities will be proportional to Or_1 and Or'_1. On rotating the coils back towards the main coil maximum so that the incident wave arrives along the line P'O, the signal ratios on reversal become Or_2 and Or'_2 which are seen *both* to be less than before and also, since r_2 has now fallen almost to zero, the discrepancy between the two signal intensities is much more pronounced. If the operator fails to realise the cause of this, he will, instead of continuing to rotate the coils through the zero position for r_2, turn the coils in the opposite direction in an attempt to get a closer agreement between r and r′ and after passing through positions P″ O, etc., will eventually get an exact balance of r and r′ at OY.

In this case the whole circuit will be reversed, the main coil and auxiliary coil have changed functions and a 90° error results.

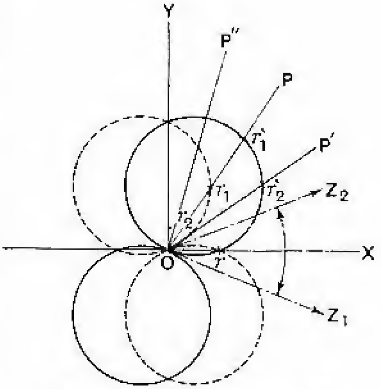

Fig. 109.—Ambiguity of the Robinson D.F.

Avoidance of 90° Ambiguity. All chance of 90° ambiguity can be avoided by ensuring that the approximate main coil maximum is located, in the first place, within the arc bounded by O Z_1 and O Z_2 in Fig. 109, the directions O Z_1, O Z_2 being those in which the main and auxiliary coil e.m.f.'s are equal and a zero signal is obtained on reversal.

Instead of searching first of all for the main coil maximum, therefore, the reversing switch is thrown first in one direction and then the other and the positions of the two minima noted. The required bearing will be midway between these two minima and can be found in the usual way. This method of taking bearings renders the balancing coil and the switch S_2 unnecessary as the auxiliary coil is never out of circuit.

Information regarding this system of D.F. will also be found in the following references: (2004), (2005), (2006), (2007), (2013), (2024), (2211).

THE APERIODIC FRAME AERIAL

The type of circuit generally known as the aperiodic frame aerial has been developed chiefly in connection with the Bellini-Tosi system, though it has in recent years come into use with rotating frames. Although described below in its application to the simple frame, it must be understood that the system of two fixed aerials with a radiogoniometer (see page 138) behaves in every way as a rotating frame.

It has been seen that the phase of the current in a tuned aerial circuit, of either the frame or open type, is liable to be appreciably changed relative to the phase of the e.m.f. by a slight change in either the tune of the circuit or the frequency of the incident wave. In directional reception on commercial stations it is more important than in direction finding to maintain a perfect zero signal at the cardioid minimum, for the purpose of eliminating jamming stations which may vary in frequency; a method of achieving this being by the use of a frame which is untuned at the cardioid minimum, and hence almost aperiodic, but which has a considerable element of tuning at any other part of the diagram where signals are audible.

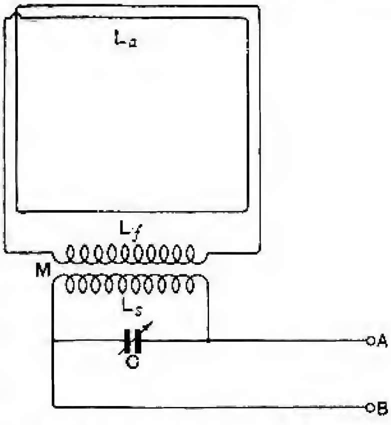

Fig. 110.—Simple Aperiodic Frame Aerial Circuit.

The simple aperiodic frame circuit is shown in Fig. 110, in which the aerial and the circuit containing the tuning condenser C are tightly coupled together by means of the transformer M L_f L_s. Now, it is well known in ordinary alternating current working that the capacities and inductances on either side of a transformer are mutually interchangeable. In fact, in the case of a perfect transformer, with a 1 : 1 ratio, the circuit would behave just as though the transformer were not in existence and, with any transformer circuit, provided that we allow for the ratio of transformation, we can consider the whole circuit from either the primary or secondary side.

The same reasoning holds good in the case of the aperiodic frame. The incident wave induces an e.m.f. in the frame L_a and the complete circuit consists of L_a, the high-frequency transformer L_f L_s and the condenser C; consequently there will be some value of C which will bring the whole circuit into resonance with the e.m.f. induced in L_a.

The natural wave length of the circuit, neglecting the effect of resistance is given by:

$$\lambda = 1885 \sqrt{\frac{C\,[L_s\,(L_a + L_f) - M^2]}{(L_a + L_f)}}$$

where λ is the wave length in metres, L and M are in microhenries and C in microfarads.

Receiving Qualities of Aperiodic Frame. The statement made above, that allowing for the ratio of transformation, the circuit of Fig. 110 behaves as though the transformer were non-existent is only true when the leakage field is very small. When a current is flowing in L_f a magnetic flux is produced in the winding, and we have ensured, by making the transformer very tightly coupled, that as many lines of the field as possible shall also be linked with L_s. Those lines which fail to pass through L_s, but do pass through L_f, give the transformer what is called leakage inductance. This leakage inductance causes the condenser C to have less tuning effect than it would have, were the transformer not there, and for this reason and also because the damping of the circuit is increased by the resistance of the windings, the receiving power of such an aperiodic frame circuit is considerably less than that of a tuned frame.

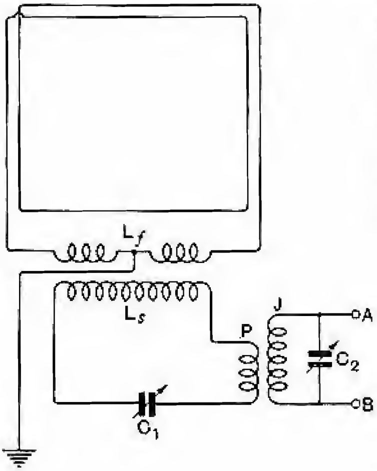

Fig. 111.—Aperiodic Frame with Loose-Coupled Intermediate Circuit.

It was seen on page 85 that the amount of distortion caused by vertical is dependent upon the linear dimensions of the frame, becoming greater as the receiving power is reduced. The result is that vertical assumes much more alarming proportions in the aperiodic than the tuned frame, and it becomes essential to employ either a shielded transformer or an earthed mid-point of the aerial coupling coil, or both.

Aperiodic Frame with Loose-Coupled Intermediate Circuit. A modification of the above circuit is shown in Fig. 111, where a coil P is inserted in series with L_s and an adjustable condenser C_1. P is loosely coupled to the receiver input circuit JC_2, the frame being tuned by C_1. This circuit is much more selective than that of Fig. 110, and the presence of a loosely coupled secondary circuit renders the use of a shielded transformer less necessary, the earthed mid-point of the frame coupling coil being sufficient to correct the small amount of vertical present. It is essential, however, that the condenser C_1 be adjusted to bring the aerial circuit into close tune with the wave to be received as any mistuning will reduce the receiving power of the loop and so tend to accentuate the effects of vertical.

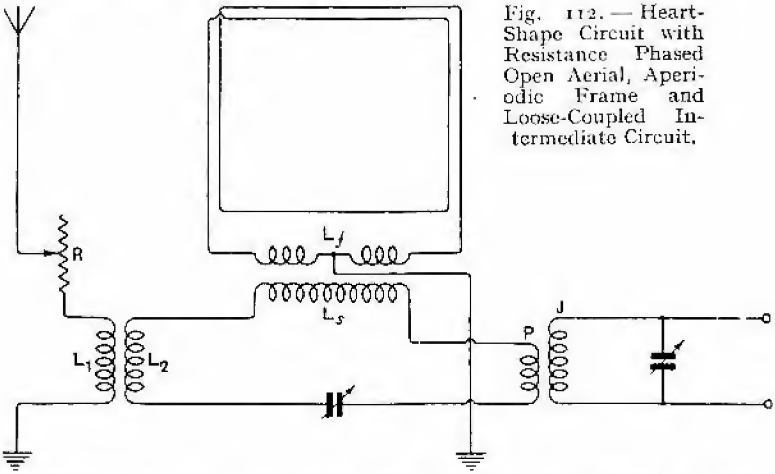

Fig. 112.—Heart-Shape Circuit with Resistance Phased Open Aerial, Aperiodic Frame and Loose-Coupled Intermediate Circuit.

Heart-Shape Circuit with Resistance Phased Open Aerial, Aperiodic Frame and Loose Coupled Intermediate Circuit. In Fig. 112, both the open aerial and the frame are aperiodic, being a modification of Fig. 85, which illustrated the similar circuit for tuned frame and open aerial. Consider now the behaviour of the system under the influence of an incoming wave, assuming at the same time that the correct values for the open aerial phasing resistance and the various couplings have been found to give a heart-shape balance and also that the rotating frame—or search coil of the radiogoniometer in the B-T system—has been turned to such a position that no signals are being received. In this position, there will be no current in the coil J and consequently no current in the intermediate circuit; so there can be no energy transfer from either the open aerial or the frame to the intermediate circuit. It is therefore quite permissible to ignore the intermediate circuit, and to examine the phases of the frame and open aerial currents independently.

As previously mentioned, the e.m.f. in the frame will lag 90° on the flux in the wave, whilst the current will lag or lead on its e.m.f., depending upon whether the natural period of the loop and coupling coil L_f, in its simplest mode of vibration, is above or below the frequency being received. Since the impedance of the loop is almost wholly inductive, the current will normally lag about 90° on the e.m.f., although since there is a certain amount of resistance in the frame winding and coupling coil, the angle of lag will be less than 90° and may be taken as, say, 87°, as shown in the vector diagram of Fig. 113. This will mean that the current I_f in the frame will lag $87° + 90° = 177°$ on the flux in the wave, and hence, if the phase difference between this current and the current I_v in the open aerial is to be 180°, in order to get a cardioid balance, then I_v must lag on its e.m.f. by $177° - 180° = -3°$. In other words, I_v must lead by 3°. A reduction in the natural period of the circuit produces a leading current, and therefore the inductance L_1 is made rather smaller than is required for resonance in the open aerial, the correct value being found by adjusting L_1 and R until a balance is obtained.

The adjustment of the open aerial circuit is dealt with again in more detail on page 326.

It has been said that the frame current will generally be a lagging one. A condition of leading current can, however, arise, one cause being the presence of long connecting cables between the frame and the coupling coil L_f and this is more likely to occur in the Bellini-Tosi system, where L_f is a radiogoniometer field coil. Fig. 114 (*a*) shows a small capacity C which represents that of the connecting wires or cable. This capacity does not affect the principle of the simple aperiodic loop described on page 117 as there is obviously no current in the loop at the cosine minimum and we are not interested in what happens during the remainder of the cosine diagram. In the present instance, however, there is an e.m.f. in the loop, and there appears to be a possible mode of oscillation as in Fig. 114 (*b*) and, furthermore, the parallel inductances with a small capacity suggest a periodicity above the normal true value, and hence again a leading current.

Whethere there is a leading or lagging current at the cardioid minimum is of no account as the method of "resistance phasing" the open aerial is still applicable, the only point being that the current in the open aerial must be arranged to lag or lead as required and it is important to ensure that the loop does not pass through the critical value of what is called "Loop Tune" (see page 421) in the middle of a wave range.

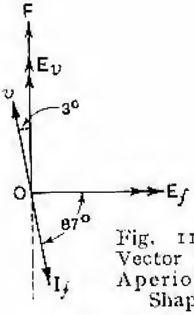

Fig. 113.—Simple Vector Diagram for Aperiodic Heart-Shape Circuit.

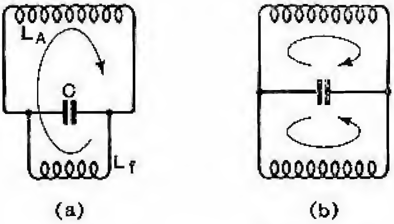

Fig. 114.—Alternative Modes of Oscillation in B.-T. Loop and Field Coil.

To revert to the vector diagram of Fig. 113 for the case of the lagging loop current, it will be seen that the above relation between the phases only holds good so long as there is no current flowing in the intermediate circuit L_2 L_3 P. If any current is flowing, it will react back to the aerials and displace the phases of the aerial currents. It will, therefore, now be understood why it was assumed that the frame or search coil was in such a position that no signals were being received ; it was in order that the phases of the currents in the aerials could be legitimately considered independently of the remainder of the circuit. This shift of phase due to the intermediate circuit current is of no practical importance since we are mainly concerned with getting a definite minimum and there is no need to worry about the fact that the rest of the polar curve does not follow exactly the theoretical cardioid diagram.

Reversal of Sense. The great advantage of the aperiodic heart-shape is its stability, and hence its value in commercial D.F. apparatus, due to the unlikelihood of an accidental sense reversal such as may so easily be obtained with tuned loop and open aerials. The phase reversal due to "loop tuning" mentioned above is a design problem only and so long as it is provided against when prescribing the working limits in frequency of the receiver, it is not likely to lead to danger.

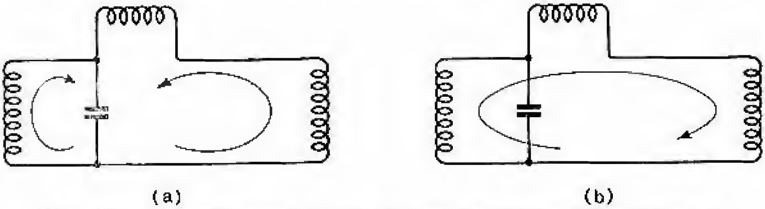

Fig. 115.—Sense Reversal due to Alternative Modes of Oscillation in Intermediate (Search Coil) Circuit with Parallel Tuning Condenser.

A sense reversal may also be obtained for the same reason when using tuned parallel inductances in, say, an intermediate circuit. Suppose that the $L_2L_5PC_3$ circuit of Fig. 86 were to be altered, as shown in Fig. 115 (*a*), for use on a shorter wave band, the mode of oscillation being as shown by the arrows. If used on long waves without altering the condenser to the series position and making provision for the series mode of oscillation, it is not unlikely that owing to the high impedance of the condenser at the lower frequencies, the mode of oscillation would change to that shown in Fig. 115 (*b*) with a sense reversal.

It is also possible, although most unlikely, to get a sense reversal due to limiting in the amplifier of a D.F. receiver even with aperiodic aerials and this is described on page 136.

FALLACIES IN HEART-SHAPE CIRCUITS

Four methods have been mentioned of obtaining the correct phase relation of aerial currents to give a heart-shape balance, namely:

(1) Spaced open aerials with non-central summation. (Page 75.)

(2) Combination of open and frame aerials, each misphased 45°. (Page 98.)

(3) Combination of open and frame aerials, one tuned and the other aperiodic. (Page 100.)

(4) Combination of open and frame aerials, both aperiodic. (Page 119.)

Of these, only the first gives a true balance under all conditions. The other three depend for their successful action on what are loosely termed "leading" and "lagging" currents, and although 3 and 4 are excellent circuits for sense determination and give very fair balances, even on atmospherics, when used for directional reception, it is not difficult to show the fallacy underlying the principle of mis-phasing as a means of obtaining this type of polar diagram. For a balance on atmospherics and damped waves, 3 has the disadvantage that the open aerial has a far higher resistance than the frame and the oscillations due to an impulsive e.m.f. will be damped out more rapidly in the open aerial. (See also page 328.)

When an alternating e.m.f. is applied to a circuit containing an excess of capacity reactance, several cycles elapse before the conditions in the circuit exhibit what is termed a leading current and these cycles are known as the **starting conditions** as distinct from the **steady state.** In describing this latter condition we are not justified in saying that because an oscillogram of the e.m.f. and current conditions in the circuit gives the appearance that the current is leading the e.m.f. by a quarter of a cycle, therefore the current at any instant is definitely associated with the e.m.f. which *will exist an instant later.*

The same argument may be applied to the lagging current, for in this case also there is a starting condition during which the relative phase of the current and e.m.f. is in a transient state, and the current does not settle down to a definite amount of lag until a number of cycles have elapsed.

Applying the above reasoning to the case of the propagated electromagnetic wave and an associated aerial and receiver, the fallacy becomes more clearly marked. When a continuous or slightly damped wave is incident on an aerial, the conditions in the alternating current circuits composing the receiver will have time to reach their steady state, and any circuit having inductive reactance will reach the condition of lagging current and capacity reactance circuits will appear to have leading currents. Suppose now, that a sudden pulse of current, such as that caused by a strong atmospheric, flows in an aerial circuit which has been tuned to give a leading current; we are surely not now correct in saying that the current is being produced by an e.m.f. pulse which is shortly going to be induced in the aerial by a flux which is still a considerable fraction of a wave length from the system?

The Artificial Line. To ensure that the phase relations of the aerial currents are correct for both starting and steady conditions of the circuits, the best thing which can be done is to avoid all attempts to produce leading or lagging currents by mis-phasing, and to make use, instead, of currents which are either in phase with the e.m.f.'s causing them or which have been made to lag a definite amount on their applied e.m.f.'s by transmitting them along a real or an artificial telegraph line, which transmission must always take a certain amount of time. Any such artificial line must have its electrical constants so related that all frequencies are transmitted with as nearly as possible equal attenuation and equal speed, otherwise the system will only be balanced for a single wave length.

The non-central method of summation in Fig. 60, employs a real line, but it would be equally effective to arrange the receiver centrally, as in Fig. 57, and to insert an additional artificial line of length equivalent to $\phi = \frac{2\pi d}{\lambda}$ in the real line between the receiver and the B aerial.

With circuits of this character, a balance can be maintained for impulsive e.m.f.'s such as those caused by atmospherics as well as for C.W. and deeply modulated transmissions.

RECEPTION ON SPACED FRAMES

In Chapter 3 there was shown on page 77 the method of arriving at the polar diagram of reception for two spaced frames when combined either centrally—that is to say with mis-phasing due only to the spacing of the frames in the wave—or non-centrally, in which case there is additional mis-phasing owing to the difference in lengths of the connecting lines between the frames and the combining point. Such arrays have a limited use for long wave directional reception and each frame may have an associated open aerial so that the resultant is a combination of two cardioids.

In Chapter 6 it will be found that spaced frames may be used for the elimination of polarization errors or "night effect," one of their most promising applications at the present time being for accurate direction finding on short waves, and this is dealt with in Chapter 10. The short-wave spaced frame D.F. as developed by T. L. Eckersley (Marconi Co.) will be found to have a distinct technique, but an earlier long wave system, described by H. T. Friis (2520), for directional reception—not D.F.—has some points in common and is of interest.

Spaced Frame System of H.T. Friis. In Fig. 116 F_1 and F_2 are frame aerials, spaced $\frac{1}{12}$ of a wave length apart, with earthed mid-points and connections to the valves V_1 V_2 in the way described on page 104. A is a radio-frequency beat oscillator, coupled by M to the input to V_1, and the oscillator is also coupled to the circuit B which is arranged to have a current in quadrature with that in A. The coils C and D are connected to these two circuits and, being at right angles, produce a rotating field in which there is placed a movable coil E in the input to V_2. The combination C, D and E arranged in this way constitutes a **phase-shifting transformer,** for the phase of the beat oscillator input to V_2 may be given any desired relation to the V_1 input by rotating the coil E. The valves V_1 and V_2 are rectifiers and their output is taken to the intermediate frequency circuits of a superheterodyne receiver.

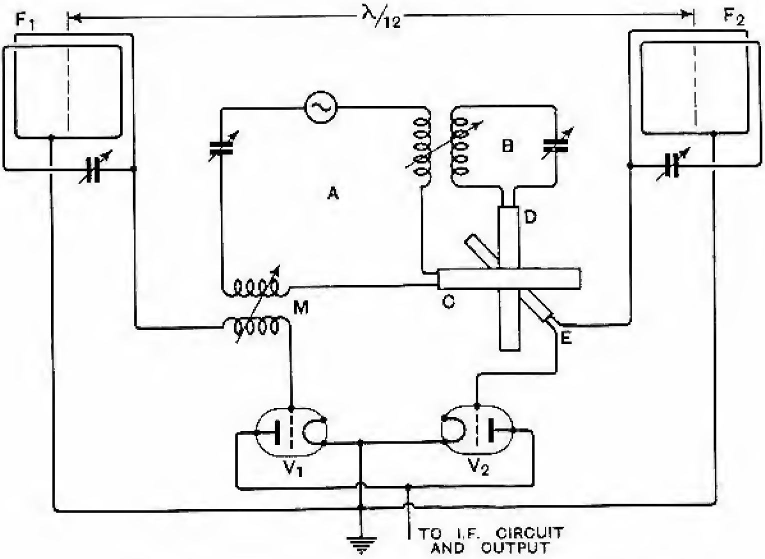

Fig. 116.—Spaced Frame Receiving Circuit of H. T. Friis.

The phase relation of the intermediate frequency outputs of V_1 and V_2 is a function of both the frame spacing and also of the relative phases of the beat oscillator inputs, so that a series of polar diagrams of reception can be obtained similar, though not identical, to those that would be produced by varying the spacing of the frames as in Fig. 68.

The system was tried out on 5,000 to 6,000 m. with fixed frames and also on a band of waves below 600 m., using a rotating turntable which carried the frames at the ends and had the receiving hut mounted centrally. Open aerials were used for cardioid combinations.

EXAMPLES OF DIRECTION FINDER CIRCUITS EMBODYING APERIODIC AERIALS*

The Telefunken Ship D.F. Type E 374 N. Until recent years it has not been usual to find aperiodic or transformer tuned aerials in the rotating frame D.F., but this system has been adopted by the Telefunken Company in one of their designs.

Fig. 117 shows the arrangement for the cosine diagram used in the preliminary direction finding process and Fig. 118 the circuit for sense determination. A small auxiliary aerial is arranged symmetrically with the loop, and the three leads from the aerials are brought either directly down the shaft of the frame or by cable in the case of a remotely controlled frame. The condenser C_1 is not for tuning the frame, but is pre-set and adjusted so that the total capacity of the aerial circuit—comprising the capacity of the loop, connecting leads or cables and the condenser C_1 itself—shall be 0·00018 μfd.

C_2 is the first of a series of ganged tuning condensers, and for satisfactory ganging the above-mentioned frame circuit conditions have been found necessary. The transformer L_1 L_2 and L_4 has a tertiary winding L_3, which is

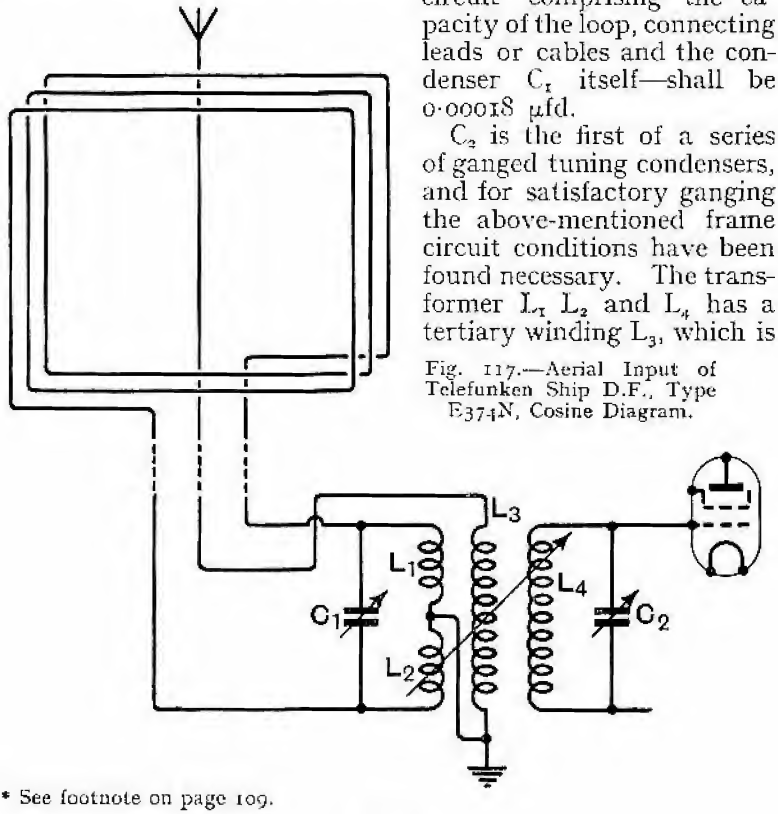

Fig. 117.—Aerial Input of Telefunken Ship D.F., Type E374N, Cosine Diagram.

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* See footnote on page 109.

variable in coupling from a plus maximum through nil to a minus maximum, and this is connected with the auxiliary aerial. The lower end of this winding goes to earth and so also does the mid-point of L_1 L_2, in order to reduce vertical effect. The auxiliary aerial is used for zero cleaning when on cosine diagram reception.

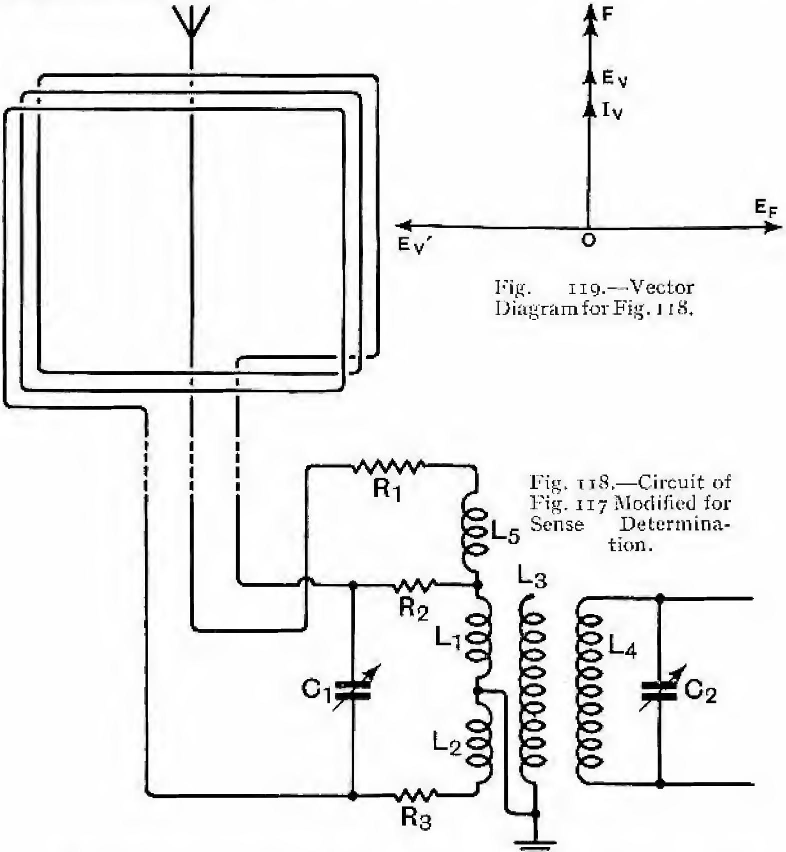


Fig. 119.—Vector Diagram for Fig. 118.

Fig. 118.—Circuit of Fig. 117 Modified for Sense Determination.

For sense determination the circuit is altered, as in Fig. 118. L_3 is now not used, and the auxiliary aerial is connected instead to either the top or bottom of the primary of the frame transformer, through the high resistance R_1 and the inductive loading L_5.

The vector diagram for this arrangement is shown in Fig. 119. F is the flux in the wave, E_f the frame e.m.f. lagging 90° on F and since at the point of heart minimum there can be no current in the first H.F. circuit, the e.m.f.'s due to the frame and open aerials must balance. The current in the open aerial is maintained approximately in phase with its e.m.f. by the inductive loading and resistance phasing (page 99) and the e.m.f. induced across the inductance L_1 will be in quadrature with this current and hence, as at E_v', in phase opposition to the frame e.m.f.

The resistances R_2 R_3 are to reduce the frame current in view of the much attenuated auxiliary aerial current owing to the phasing resistance. The circuit is not intended to give a true cardioid, but only enough unilateral reception to determine sense. Details of the circuit and the apparatus are given on page 448.

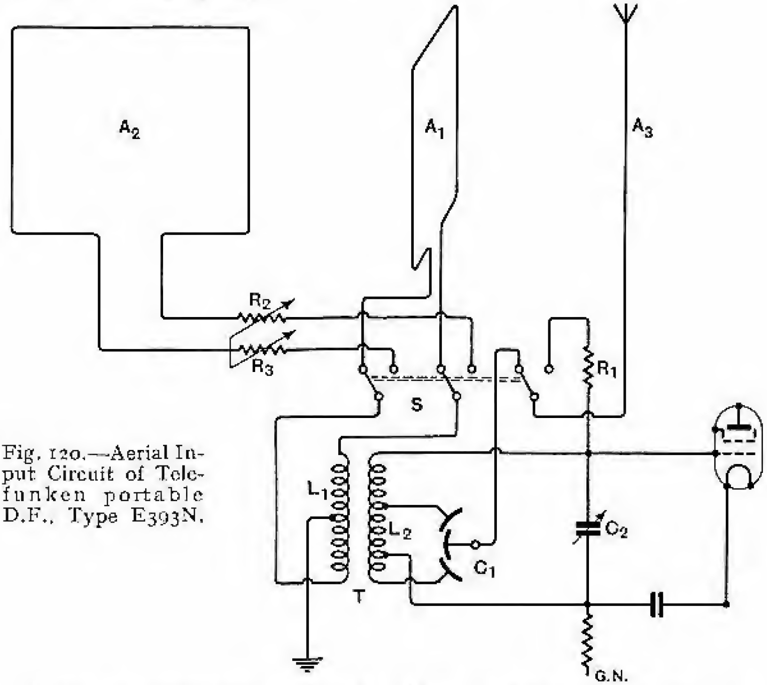


Fig. 120.—Aerial Input Circuit of Telefunken portable D.F., Type E393N.

The Telefunken Portable D.F. Type E 393 N. In this instrument a circuit is used which is very similar to the Ship D.F. circuit of Fig. 117 and 118, in which the loop circuit is again untuned at the point of heart minimum, but two frames at right angles are used. One of these provides the cosine diagram for D.F. and the other a cosine diagram which, in combination with an auxiliary aerial effect, gives the

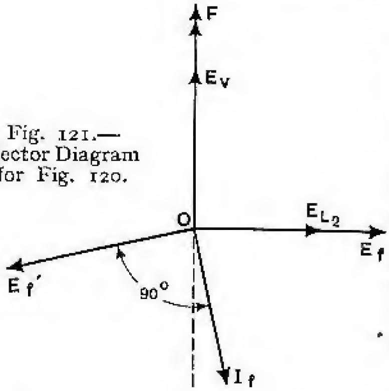


Fig. 121.—Vector Diagram for Fig. 120.

cardioid for sense. It will at once be appreciated that since the sense loop is in the plane of the received ray at the position of D.F. minimum, the resulting cardioid on switching in this loop will have its minimum coincident with one of the cosine minima. This avoids the necessity for rotating the frame through 90° for sense determination.

The simplified circuit is given is Fig. 120, where A_1 is the D.F. loop and A_2 that for sense. In the D.F. position, that is to say with the switch S to the left, the input circuit to the first valve consists of the secondary winding L_2 of the transformer T and the tuning condenser C_2. The auxiliary aerial A_3 is connected to the rotor of the differential condenser C_1 and used in either direction through L_2 for zero cleaning.

For sense determination, with the switch S to the right, A_1 is disconnected and A_2 is connected to the winding L_1 in series with the variable resistances R_2 R_3, whilst A_3 goes to the grid of the first valve through the phasing resistance R_1.

To see how the cardioid diagram is produced, the circuit should be considered in the same way as was the aperiodic aerial circuit with loose coupled intermediate circuit on page 119. Under the condition of no current in the circuit L_2 C_2, the frame A_2 can be treated as an isolated circuit. The frame e.m.f., E_f, lags 90° on the flux in the wave F, as in the vector diagram of Fig. 121, and since the aerial circuit is mainly inductive there will be lagging current I_f, whose lag will be controlled by the value of R_2 R_3. The e.m.f. induced in L_2 by this aerial current will again lag 90° as shown at E_f'.

Now the open aerial is connected to the parallel resonant circuit L_2 C_2, so that the e.m.f. E_{L_2} in L_2 will be in quadrature with the applied e.m.f. from the aerial, as shown in the vector diagram, and hence will be in phase opposition to the e.m.f. induced from the frame. The amplitude of the open aerial signal is limited by the resistance R_1 and the result is an approximate cardioid balance.

The Marconi Ship D.F. Type D.F.G.9. A simplified circuit of this set is given in Fig. 122 and has a number of points of interest. The frame aerial is actually Bellini-Tosi but is here shown as an aperiodic loop, and is coupled to the tuned grid circuit of the first H.F. valve V_1. The vertical aerial is valve coupled by V_3 and is arranged to perform the three functions of zero cleaning, sense determination and all-round reception. In the top position of the switch, the anode circuit of V_3 is coupled to the first tuned circuit and obtains its anode volts from a potentiometer P connected across the H.T. supply. With full H.T. the amplification of V_3 is a maximum, swamping the frame effect and giving omni-directional reception. As the H.T. is reduced, the open aerial effect becomes comparable with that of the frame and a unilateral polar diagram results, the vector diagram for which being approximately as in Fig. 113.

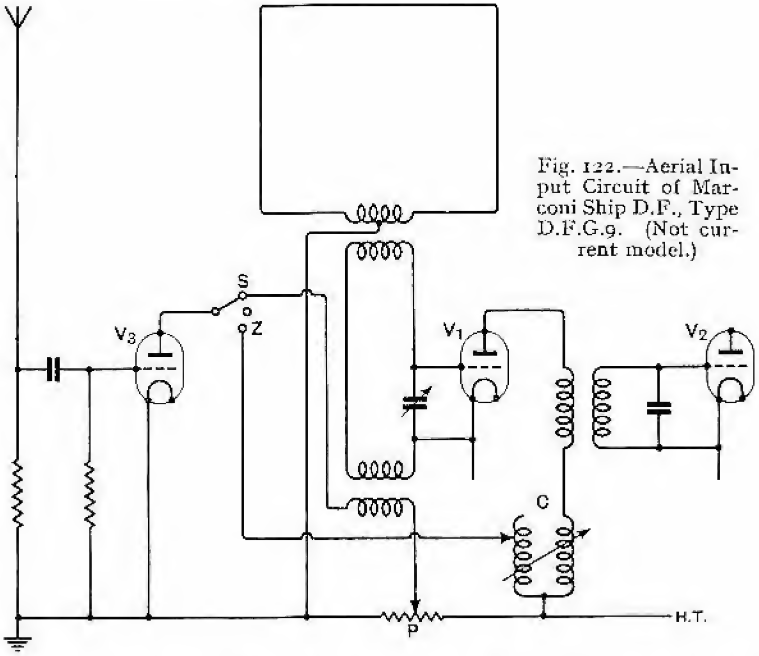


Fig. 122.—Aerial Input Circuit of Marconi Ship D.F., Type D.F.G.9. (Not current model.)

In the centre position of the switch, the open aerial is not in action and in the lower position at Z, the anode circuit of V_3 is coupled to the output instead of the input of V_1. Now since there is a 90° change of phase between the current in the tuned grid circuit and the aperiodic anode circuit of an amplifier such as V_1, the open aerial effect, if coupled in at this point, will be in quadrature with the frame signal, which is the condition required for zero cleaning. Control of the amplitude is obtained by the coupling C.

LINEARITY IN AMPLIFICATION AND RECTIFICATION

Aerial and receiver input circuits having been considered, there should logically follow some account of amplification and rectification of signals, but the design of valve amplifiers is now dealt with in such a multiplicity of books that space cannot be taken up with the general subject. One aspect, however, is of extreme importance in receivers for direction finding—as also in many other connections—and that is the effect of distortion in either of the above processes.

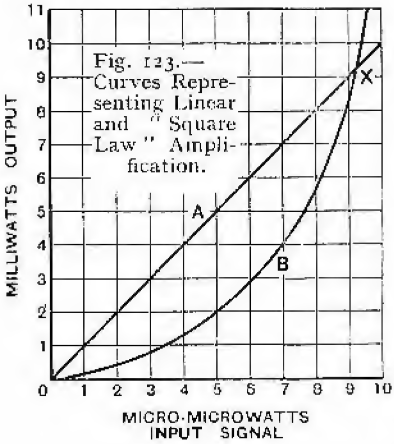


Fig. 123.—Curves Representing Linear and "Square Law" Amplification.

In the reception of telephony, both frequency and amplitude distortion have to be avoided. In D.F. work, one is less concerned with frequency distortion, but amplitude distortion does have a marked effect. In certain cases receivers are actually designed to produce the latter, and the circumstances in which it is justifiable are worth investigating.

Definition of Linearity. If an amplifier be designed to have an overall performance such that all signals below a certain maximum of, say, 10 micro-micro-watts input, and no matter how much weaker, are amplified by a constant factor, say, 10^9 times in energy amplification, then this could be represented by the straight line A in Fig. 123, and the amplifier could be said to be **rectilinear** or what is loosely known as **linear.** If, on the other hand, owing to the process of rectification, or for other reasons, strong signals are amplified progressively more than are weak ones, then the performance will follow a hyperbolic curve as in B, and the output is usually said to follow a **square law.** This term again is generally loosely used to cover any curve of approximately this shape. Such a performance is, of course, still "linear" but is now curvi-linear instead of rectilinear, though in practice these terms are not used and the single expression linear is reserved for the directly proportional or straight line performance.

It is well known that departure from straight line amplification may also be due to limiting caused by overloading, by under or over biassing of valves, and other causes, but these are matters of faulty design and adjustment rather than of principle.

Linearity and the Cosine Minimum. The whole process of direction finding by aural means depends upon the observation of the changes in signal strength in the neighbourhood of the minimum position of the frame aerial, and an amplifier that would exaggerate the rate of change in signal strength might be desirable in certain instances, whilst one that reduced the signal contrast would almost certainly be a disadvantage.

The fact that square law rectification tends to reduce still further the volume of weak signals suggests, at first, a possible means of sharpening the cosine minimum, but other aspects of the problem must be considered. Since the gain of an amplifier using square law rectification is not constant, but increases with increase of input signal, it will be found that whether the normal cosine diagram is improved or degraded, from a D.F. viewpoint, depends primarily upon the degree of R.F. amplification used or on the width of the swing bearing taken, both of which bring the signal on to a steeper part of the output curve.

In Fig. 124, the base line represents input, and is calibrated in terms of degrees movement of the frame aerial, whilst A_1 is the output graph for linear rectification. Curve B_1 is a square law curve and has been drawn so that the A_1 and B_1 outputs are equal for the frame maximum position. It may be noted that the ordinates of B_1 are equal to the squares of those of A_1, taking the maximum as unity.

In this case the square law output is definitely inferior for D.F. purposes as the rate of change of signal is very low for small swings, and only begins to be steeper than the linear output at about 30°.

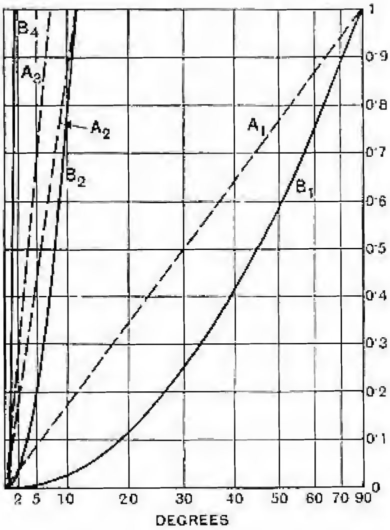


Fig. 124.—Varying Degrees of Linear and Square Law Amplification, and the Effect Upon Swing and Spot Bearings.

These two outputs are shown as polar curves in Fig. 125 where the linear one is the familiar figure eight, and the bluntness of the $\cos^2$ diagram minimum is very noticeable.

Now assume that additional R. F. amplification of about five times voltage gain is used in the square law case, giving twenty-five times the output as represented by the output curve B_2 of Fig. 124. In this case, a swing of 1½° will still result in a weaker signal than with the A_1 output, but note that the square law *rate of change* is becoming very large and for a 2° swing the slope is nearly double that of A_1. This rapid rate of change for a small movement of the frame gives increased precision, however, only if swing bearings are being taken beyond 1° where the slopes are about equal.

Now let the same amount of R.F. amplification be applied in the linear case resulting in the A_2 output line, and note that the A_2 slope is greater than that of B_2 up to 6° or 7°, whilst further gain in the square law case produces B_4, and so on.

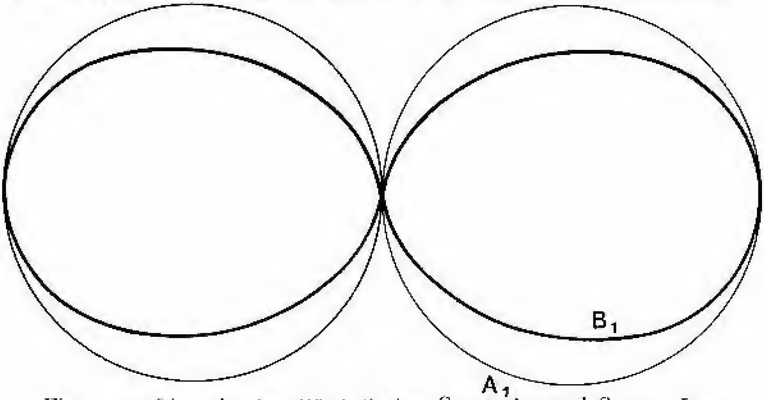


Fig. 125.—Linearly Amplified Cosine Curve A_1, and Square Law Amplified Cosine Curve B_1, showing Effect upon Minima.

These curves cannot be reproduced in polar form in Fig. 125, as they would be too close together to be distinguishable near the minimum, but the A_2 A_3 curves would be cosine circles of 5 times and 7·5 times the radius of the A_1 diagram, and hence would have increasing sharpness at the zero point.

The advantage of the square law curve is thus in every case its increased precision for swing bearings, although the actual minimum position itself is invariably less well defined and less suitable for " spot " bearings.

C.W. versus I.C.W. or M.C.W. The disadvantage of the square law rectifier is apparent in Fig. 124, and it is that since the ratio of output to input is increasing, strong atmospherics or a jamming signal will be amplified more than the wanted signal, and will make the D.F. operation difficult and at times impossible, due to the masking of one side of a swing bearing by strong interference.

Whether or not square law detection is an aid to precision therefore depends on the receiving conditions and also on the correct relative adjustment of the amplification and the width of bearing swing. Experienced D.F. operators who handle their apparatus skillfully and take swing bearings of 10°, 20° or more total swing, often prefer a modulated signal, and hence square law working, but as mentioned again on page 465, there are other factors that influence the choice of C.W. or I.C.W. for D.F. beacons and any slight advantage that I.C.W. may have for the above reasons is probably outweighed by the more pressing matters of modulation spread and mutual interference of neighbouring beacons. The question of C.W. versus I.C.W. is also discussed in Chap. 6 in connection with polarization errors, but this has no connection with the matter now being discussed.

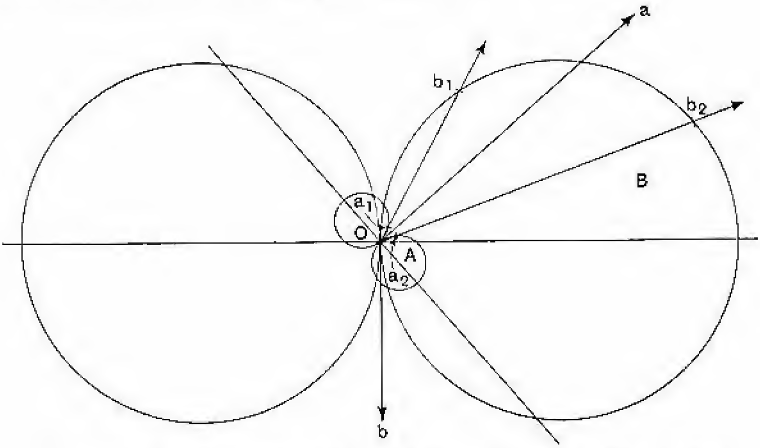


Fig. 126.—Cosine Diagram of Reception of Wanted Signal A and Jamming Signal B.

AUTOMATIC GAIN CONTROL

Automatic gain control may sometimes be applied to D.F. work, but being a form of non-linearity it must be used with caution. It may, however, be of interest to consider its effect when used to reduce the effect of a strong jamming signal.

Consider Fig. 126, in which the small cosine diagram A is the wanted signal with bearing Oa whilst B is the diagram of the jamming signal. Note that in practice, B may be 100 or more times the field strength of A, and whilst it may be possible to take a snap bearing of A during periods of silence of B, this becomes a nuisance owing to the deafening effect of the B signals. If B's transmission be continuous, the process is still more tedious, both owing to the difficulty of hearing A's signal near the minimum and also because, in the case shown, B's signals Ob_1 and Ob_2 are of unequal strength in the two directions of swing bearings on A.

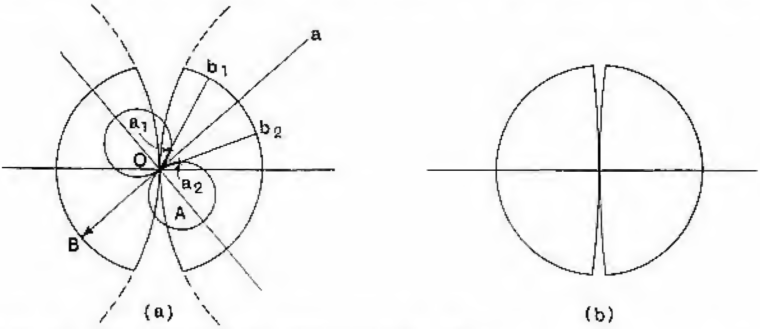
Gain Control by Bias Variation or "Linear" A.G.C. The latter title is really a misnomer but is sometimes used in reference to the more common type of automatic gain control, in which the gain is controlled by the carrier of a telephony channel in such a way that when the signal strength tends to increase above a pre-arranged maximum, the gain of the amplifier is reduced by applying more grid bias to the R.F. amplifying valves, which are usually of the variable-mu type, or by some similar means. The system is also applied to telegraph receivers, in which a carrier is being keyed by morse characters, and in this case a time lag is provided so that the gain control still operates during the short spaces between the morse characters and only cuts out when the transmission stops for more than, say, one-tenth or one-fifth of a second. This lag is arranged to suit the speed of working of the circuit.

In a control of this type, it follows that not only the strong signals, but also any weaker signals, will be proportionately reduced in strength—the proportion depending on the linearity of the amplifier, and if it were applied to the case illustrated in Fig. 126 the signal A would inevitably disappear each time that B transmitted. Whilst the deafening effect of B is now removed, there is no possibility of taking a bearing on A except during pauses in B's working.

A danger of this system is also that in taking a swing bearing on a signal of medium strength, the gain control may be operated at one side of the swing, due to a jamming signal, and not at the other with obvious production of error.

Gain Control by Limiting. In this system, all signals are amplified in their correct proportions but a limit is placed on the output of the amplifier. In commercial wireless telegraphy this is sometimes referred to as "working between stops" since it is analagous to the method of recording high speed morse on paper slip by the Undulator method in which the pen moves between definite stops as distinct from the Syphon Recorder which does not.

Assuming that the signal A mentioned above is weak enough not to be limited, the effect of this system upon its reception through B's transmission is shown in Fig. 127 (*a*). The cosine diagram of B is now reduced in amplitude to the limiting value OB and causes far less interference with the A signal, being in this case also of uniform amplitude in the neighbourhood of the A minimum, thus allowing swings to be taken with more assurance.



(a) (b)

Fig. 127.—(*a*) Effect of Limiting upon Fig. 126.
(*b*) Effect, upon Cosine Diagram, of High Degree of Limiting.

Gain Control and the Cosine Minima. The effect upon the shape of the resulting diagram of reception must also be noted when a signal is received which is many times stronger than that necessary to operate the gain control or limiting device. This is shown in Fig. 127 (*b*) in which the minima are now reduced to narrow slits in an otherwise circular diagram. Still more exaggerated diagrams can be obtained in practice when due attention is given to screening and zero-cleaning, but in general they have no advantage over the normal cosine diagram for direction finding owing to the difficulty of obtaining a crisp zero under such adverse conditions of greatly increased gain, at this one part of the diagram.

Sense Reversal due to Limiting. Fig. 128 shows a D.F. receiver with H.F. and L.F. amplifiers in which the former has been set to maximum gain—in which condition it limits or saturates on all but weak signals. In an attempt to compensate for this, the L.F. amplifier gain has been set to a low figure and is actually reducing the signal considerably. It is true that if an attempt were made to use the receiver for D.F. in this condition, it would probably be realised that there was something abnormal in its behaviour, but it is interesting to note the effect of these adjustments on a sense observation.

In many commercial D.F.'s no attempt is made to produce a true cardioid, the sense indication being obtained from a diagram of the shape shown in Fig. 129 by the full line. If then, this is the input to the R.F. amplifier, from say a modulated beacon station, the ordinate OA being comparatively weak will be greatly amplified in the R.F. stages, somewhat reduced in the L.F. amplifier, and the output will be a signal of fair strength, as shown by the dotted curve OA′. On the other hand, the ordinate OB will cause limiting in the R.F. amplifier with consequent demodulation of the signal and a great reduction of the audio frequency output from the rectifier. This weak signal will be still further reduced in the L.F. stages giving an output of, say OB′, and a complete reversal of sense.

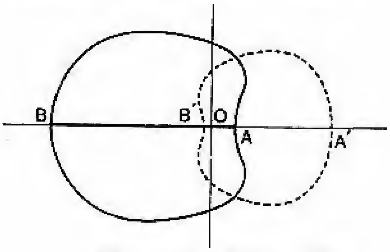


Fig. 129.—Polar Diagram of Reception, by Receiver of Fig. 128, of Modulated Signal, showing Reversal of Sense.

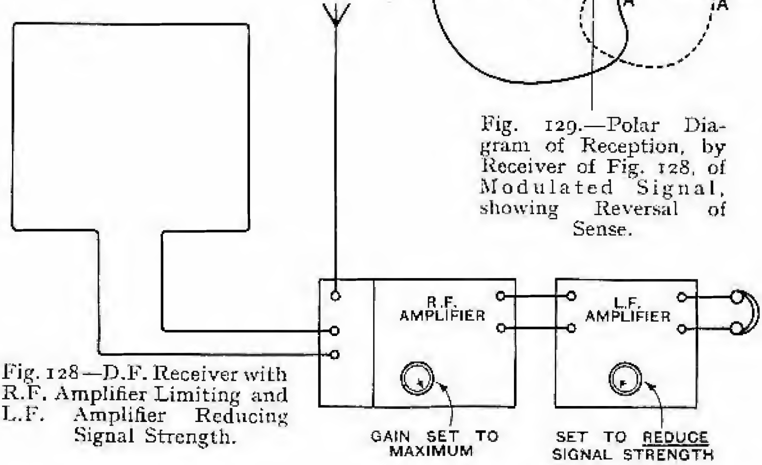


Fig. 128—D.F. Receiver with R.F. Amplifier Limiting and L.F. Amplifier Reducing Signal Strength.

CHAPTER 5

THE BELLINI-TOSI SYSTEM

As already mentioned in the Introduction, this system was introduced in 1907 and has been applied both to transmission and reception. Of later years it has become more popular for directive reception, since it has the advantages of large aerials and at the same time retains the mobility of the small frame, enabling bearings to be taken very quickly.

The method consists in employing two loop aerials, fixed at right angles, and connected respectively to two small multi-turn coils also at right angles to one another. A third coil is arranged to rotate in these two latter coils and is for the purpose of determining the direction of the magnetic field in the small coil system. An idea of the positions and appearance of the coils in the instrument—called a **radiogoniometer**—can be gathered from Fig. 130. Two frame aerials are shown supported in vertical planes and arranged so as to be exactly at right angles to one another and symmetrical about a common vertical axis. The two aerials are connected to the two field coils in the radiogoniometer and are tuned by means of variable condensers, which are inserted at the mid-points of the field coils, these latter being wound in two halves for this purpose. The rotatable search coil is connected through suitable tuning arrangements to the detecting circuits.

Consider what is the effect of a wireless signal incident on this system. Suppose, first of all, that the signal is arriving in the plane of the A frame; in this case no e.m.f. will be induced in the B aerial because it is at right angles to the direction in which the waves are travelling, whereas the aerial A will be in its position of maximum receiving power and will have an e.m.f. induced in it. The resulting current will produce a magnetic field along the cylindrical axis of the " a " field coil. On the other hand, in the case of a signal which is incident exactly in the plane of the B aerial, a magnetic field will be produced along the axis of the " b " field coil.

If, however, the direction from which the wave is arriving lies somewhere between the planes of the two aerials, both aerials will have e.m.f.'s induced in them, there will be currents in both field coils, and in the neighbourhood of the search coil there will now be two magnetic fields at right angles to each other, the relative strengths of which will depend upon which aerial most closely coincides in direction with that of the incident wave. It can, in fact, be shown that the two magnetic fields produce a resultant field which bears exactly the same space relationship to the axes of the field coils as the direction of the received signal does to the planes of the frame aerials.

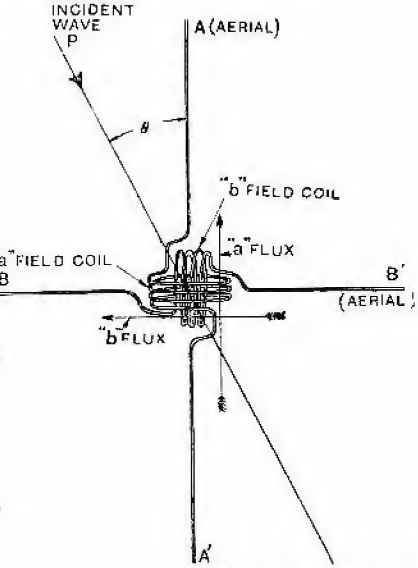


Fig. 131.—Action of Radiogoniometer.

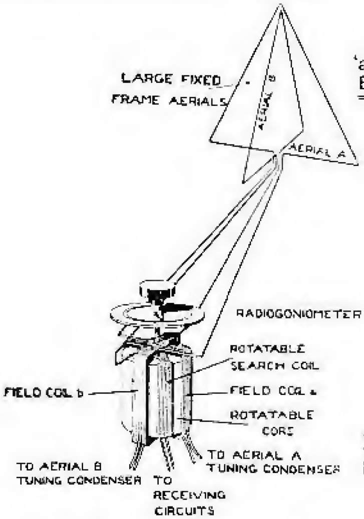


Fig. 130.—Radiogoniometer and Bellini-Tosi Aerials.

Let Fig. 131 represent a plan view of the frame aerials A A' and B B' and the field coils *a* and *b* of the radiogoniometer, and let the arrow indicate the direction of the incident wave, making an angle θ with the frame A A'.

Now if I_{max} be the current in the aerial A A', and hence in the field coil *a*, when the direction of the wave is in the plane of the A A' aerial, then the current in coil *a* under the condition shown will be :

$$I_a = I_{max} \cos \theta$$

and similarly the current in the coil *b* will be :

$$\begin{aligned} I_b &= I_{max} \cos (90^\circ - \theta) \\ &= I_{max} \sin \theta \end{aligned}$$

Since the two field coils are at right angles, the magnitude of the resultant flux may be found by a simple rectangular parallelogram of forces. In Fig. 132, O A represents in direction and magnitude the flux in the *a* field coil and similarly O B represents the flux in the *b* coil, the resultant being proportional to O R, making an angle ϕ with O A. But:

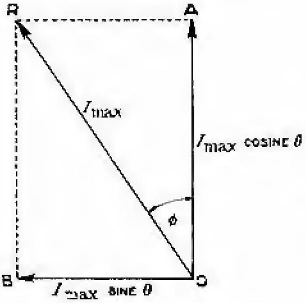


Fig. 132.—Theory of Radiogoniometer.

$$\tan\phi = \frac{I_{max}\sin\theta}{I_{max}\cos\theta} = \tan\theta$$

therefore $\theta = \phi$ or the angle of incidence of the wave relative to the A A′ aerial is equal to the angle of the resultant flux relative to the *a* field coil.

Further, since the angle AOB is a right angle:

$$OR^2 = OA^2 + OB^2$$

or the resultant flux is proportional to

$$\sqrt{I^2_{max}(\cos^2\theta + \sin^2\theta)}$$
$$= I_{max}$$

so that the *maximum* of the signal strength is dependent solely on the intensity of the incoming wave and does not vary with the angle of incidence.

The problem remaining, then, is simply to determine the exact direction of this resulting field and this is done by means of the rotating search coil. The e.m.f. induced in the winding of the search coil is proportional to its linkage with the magnetic field and consequently as the search coil is rotated inside the field coils there will be a maximum e.m.f. when the cylindrical axis of the coil lies along the direction of the resultant field and zero e.m.f. when its axis is at right angles to the field. As the search coil is rotated, therefore, the telephone receivers are found to indicate alternate maximum and minimum signals 90° apart just as was observed in the case of the rotating frame aerial.

A pointer is attached to the spindle of the coil and a scale is fixed to the frame of the instrument so that the direction of the resultant field, and hence of the incident wave, may be read off. In the case of a land station the aerials are generally laid out North-South and East-West, so that the bearing of any transmitting station can at once be found.

The theory of the radiogoniometer in its application to the B-T system is dealt with by L. H. Walter (0908), J. J. Bennett (2111) and in many articles and papers by Bellini and Tosi, which will be found in the Bibliography.

The Electrostatic Radiogoniometer is dealt with later in this chapter, and the use of the Cathode Ray Tube as a radiogoniometer in Chapter 16.

CONDITIONS FOR ACCURATE WORKING OF TUNED AERIAL B-T SYSTEM

In order to obtain the ideal disposition of magnetic fields in the inductive radiogoniometer, as above described, it is necessary that a number of conditions be fulfilled :

Condition 1. Phase Relation of Aerial Currents, Balancing, etc. The currents in the aerials are, of course, alternating and it is necessary that they should be exactly in phase. If this is not the case a rotating magnetic field is produced which is superimposed on the normal stationary field, giving impure minima. It was noted on page 99 that a very small change of tune may cause a large change in the phase of the current, so that, unless the loops are very accurately tuned to the same wave length, condition No. 1 will not be satisfied.

This accurate tuning of the two aerials is known as **balancing.** In practice the operation is performed by means of a small oscillatory circuit, coupled very loosely to both aerial systems and excited by means of a shunted high note buzzer*. The e.m.f.'s induced by this buzzer circuit in the two aerials will be in phase, because they are the result of one current in the small oscillatory circuit. If, then, we tune one aerial to buzzer wave length and, rotating the search coil to the minimum signal position, we adjust the other aerial condenser till the best minimum is obtained, we know that the currents are in phase. (See page 320 for practical details.)

It is not necessary that the aerials should be very exactly tuned to the incoming wave ; it is only essential that they should both be tuned to the *same* wave length as one another. If the incoming wave is a little longer or shorter than the tune of the aerials, then the currents which flow in the two loops will lead or lag on the e.m.f.'s induced by the signal, but since both aerials have been accurately tuned together by means of the buzzer, the amount of lag or lead will be the same for each aerial and consequently the two currents will remain in phase.

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* The balancing of B-T loops is unnecessary in present-day equipment and this somewhat crude apparatus is here mentioned because it was the most convenient type available during the period of use of the Tuned B-T direction finder.

Condition 2. Symmetry of Aerials. The aerials must be of the same high frequency resistance, otherwise the currents which flow will not be proportional to the signal e.m.f.'s and, when spark transmitters were in common use, it was important that the damping of the aerial loops should be equal, otherwise indefinite minima resulted. For the same reason there must be no bad contacts in either aerial circuit as these introduce resistance and produce indefinite or displaced minima.

The aerials must also be equal in size since unequal loops give displaced minima, except in the cases where the aerials are definitely made of different areas for calibration purposes.

On page 424 there is an account of a special type of error which arises through lack of symmetry of the aerial system due, usually, to the capacity between one or more of the limbs of the aerial and some large conductor near at hand. This is an error which is more common in ship installations than any other and therefore is dealt with in Chapter 11.

Condition 3. Symmetry of the Radiogoniometer. The windings of the radiogoniometer field coils must be of equal resistance (see 2), have the same number of turns, be of the same size, be symmetrically disposed with regard to the search coil and in such a manner that the mutual inductance between the search coil and a field coil follows a true cosine law for various angular movements of the one relative to the other. This is dealt with in greater detail on page 154.

Condition 4. Mutual Inductance between Aerial Circuits. There must be no mutual inductance or capacity between the aerial circuits. This factor is one of the most fruitful sources of trouble in a tuned aerial B-T installation, and it is important, if clear and crisp minima are to be obtained, that there should be no coupling whatever between the two aerial circuits. The coupling may be either electrostatic, electromagnetic or conductive. The first two types are avoided by accurate laying out of the aerials so that they are truly at right angles and by arranging the lead-in from the aerials to the receiving apparatus in a symmetrical manner. Conductive coupling is eliminated by providing ample insulation between the two aerials. That any such coupling is undesirable can be seen from a study of the effects of a wave arriving in the plane of one aerial when coupling exists. Ideally, the wave should produce maximum current in the loop which lies in its direction of travel and no current in the loop which is broadside on, but if the loops are coupled together, the aerial which should have no current in it will have a current induced by that flowing in the other aerial. This at once upsets the working of the system and gives a bad minimum which may be displaced. With inductive coupling, the minimum is indefinite because the e.m.f. induced in the " broadside on " loop is 90° out of phase with the inducing current in the " end-on " loop. This results in a rotating field and so gives signals at the position of true minimum. The method of testing for and eliminating coupling between the aerials is given on page 322.

BELLINI-TOSI RECEIVING CIRCUITS

The Tuned Aerial B-T Circuit. Fig. 133 gives the circuit of a tuned B-T system, in which N-S and E-W are the two frames. The variable condensers C_1 and C_2 are connected between the split halves of the field coils *a a*, *b b* of the radiogoniometer and a vernier condenser C_2' is connected in parallel with C_2. The search coil is tuned by the condenser C_3, the terminals of which are connected to the amplifier. The tuning buzzer for balancing purposes is shown at O; it merely consists of a small oscillatory circuit placed near the leading in wires from the aerials and excited by a dry cell and a buzzer. Such a simple circuit will work quite well as a direction finder and was, in fact, in use for a long time before the developments which are mentioned below took place.

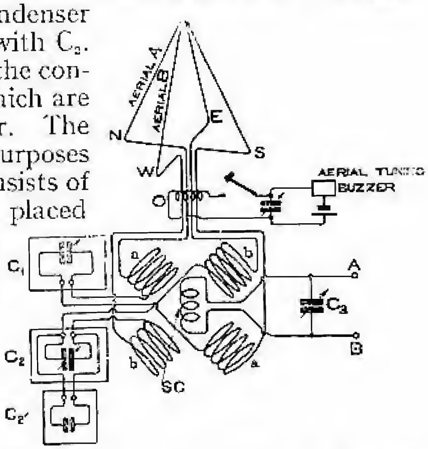


Fig. 133.—B-T Tuned Frame D.F. Circuit.

The Aperiodic Aerial B-T Circuit. It has been seen that the tuning of the two aerials in the tuned B-T direction finder is a very critical operation, owing to the fact that the two currents must be accurately in phase. This tuning is a serious disadvantage in commercial D.F. work, because the slightest accidental change of tune of one of the aerials, such as may easily occur owing to one of the variable condensers being accidentally moved, will upset the bearing taken on the radiogoniometer. This, and other causes, led to the development of the aperiodic aerial system.

In this arrangement, the radiogoniometer is constructed so that the coupling between the field and search coil is as tight as possible, the search coil being made in the form of a cylindrical cage which fills the space enclosed by the field coils (see Fig. 141). If, then, the aerials be connected directly to the field coils and the search coil be shunted by a variable condenser, the system as a whole may be tuned by this condenser. Fig. 134 shows an arrangement of the circuits, A and B being connected to the first R.F. valve of the receiver.

The theory of the aperiodic frame aerial with a tightly coupled tuned circuit has been described on page 117 and it was seen that the condenser in the coupled circuit had the effect of partially tuning the frame through the transformer. The fact that there are, in the present case, two aerials and two primaries to the transformer need not disturb us, for we have already seen that the combination of two frame aerials and a radiogoniometer is in every way the electrical equivalent of a single rotating frame.

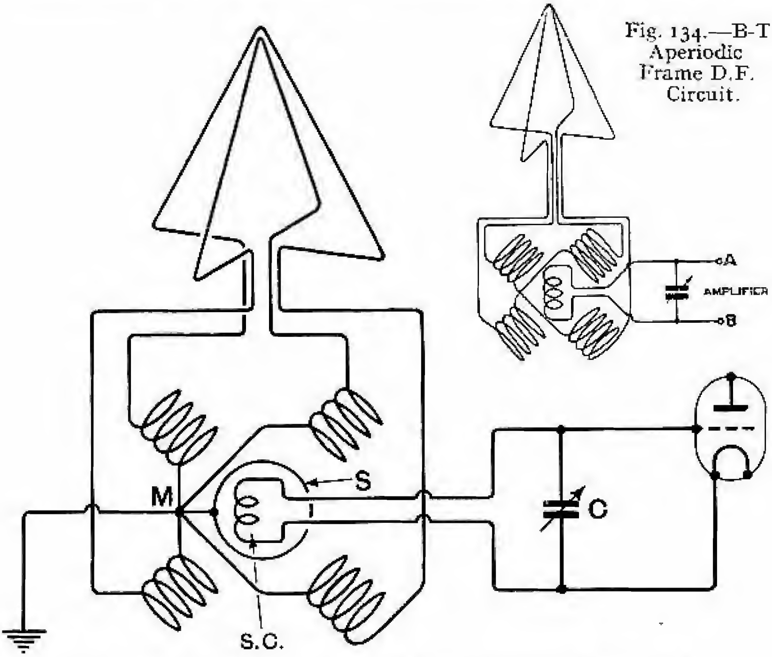


Fig. 134.—B-T Aperiodic Frame D.F. Circuit.

Fig. 135—B-T Aperiodic Frame D.F. with Shielded Search Coil.

It will now be realised that no balancing is required in this system. The loops are no longer independent oscillatory circuits and, since the e.m.f.'s induced by the incident wave are in phase in the loops, the currents which flow will also be

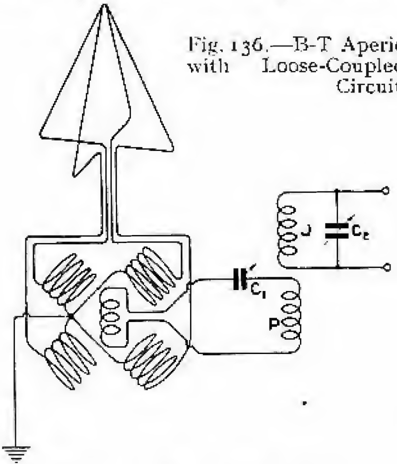


Fig. 136.—B-T Aperiodic Frame D.F. with Loose-Coupled Intermediate Circuit.

in phase. The loops are really only un-tuned when the search coil is in the position of zero signals for, as already mentioned, any current in the search coil circuit will introduce an element of tuning and alter the phase relations of current and e.m.f.

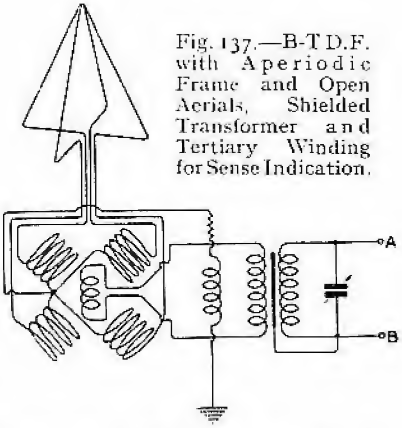


Fig. 137.—B-T D.F. with Aperiodic Frame and Open Aerials, Shielded Transformer and Tertiary Winding for Sense Indication.

The Simple B-T Aperiodic Aerial Circuit. The simplest form of B-T circuit is shown in Fig. 134, where the screened search coil SC is tuned by the condenser C and connected directly to the input of an amplifier. In practice, the radiogoniometer would always be enclosed in a screening case which is not shown here. Antenna effect is guarded against, firstly by an earth connection to the radiogoniometer field coils and secondly by the shield S. It will be observed that the mid-points of the two field coil systems have been joined together at M. This is quite safe because, provided that the aerial system is perfectly symmetrical, there is never any difference of potential between these points and no undesirable currents can flow as a result of making this connection. The error introduced by lack of symmetry of the aerials is described on page 424.

The B-T Aperiodic Aerial with Loose-Coupled Intermediate Circuit. The circuit of Fig. 136 should be compared with the corresponding simple frame circuit of Fig. 111, the remarks made on page 119 applying equally to the B-T System.

Completely Aperiodic Heart-Shape Circuit. Fig. 137 shows a circuit providing sense determination which, owing to its simplicity was used for several years in early Marconi Ship-Type Direction Finders. A shielded transformer was used in this case and is provided with a third winding to combine, in the detector circuit, the e.m.f.'s induced by the currents in the search coil circuit and those due to vertical effect. The resistance included in the circuit of the tertiary winding performs the double function of adjusting the phase and also the amplitude of the current. Its value is so chosen, when designing the circuits, that the best minimum possible is obtained over the whole range of wave length covered by the transformer and its tuning condenser, although only at one wave length is there a complete zero balance of signals.

Completely Aperiodic B-T Heart-Shape Circuit with Loose-Coupled Intermediate Circuit. The operation of this circuit, which is shown in Fig. 138, has been described on page 119 in its application to the simple rotating frame. On page 326 are given some notes on the adjustment of the apparatus of this circuit, in order to obtain an accurate heart-shape balance for directional reception of commercial wireless traffic. Such adjustments of the circuits are quite unnecessary for ordinary D.F. work. The actual direction of the transmitting station is taken on the figure eight diagram, and switching arrangements are provided for connecting the vertical aerial circuit so that the diagram is re-examined to determine which minimum represented the true bearing of the station.

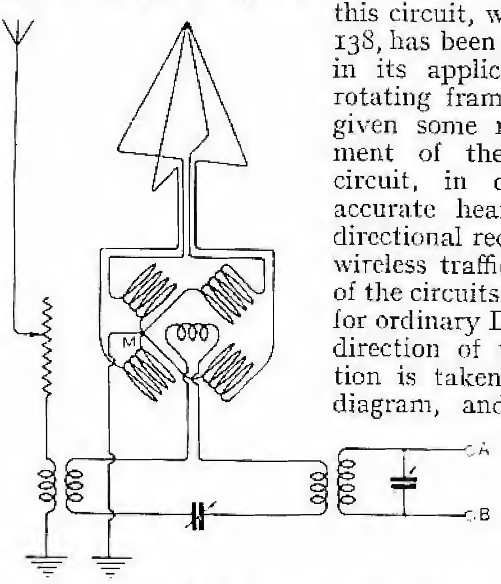


Fig. 138.—B-T All Aperiodic Heart-Shape D. F. with Loose-Coupled Intermediate Circuit.

It is preferable always to take bearings on the figure eight diagram because:

(1) The minimum of the figure eight diagram is much sharper than that of the heart-shape.

(2) The necessity for accurate balancing of the heart-shape circuit is avoided.

(3) The heart-shape diagram is not perfectly symmetrical in practice so that an error may be introduced if swing bearings are taken.

RECEIVING APPARATUS

The Radiogoniometer. This instrument is common to all B-T installations, but its design varies according to whether the system is operating with tuned aerials, simple aperiodic aerial circuit or the combination of frame and open aerial circuit for sense determination.

In addition to the inductive form of radiogoniometer, capacitative ones have been designed and although not in common commercial use, are briefly described on page 165. The Cathode Ray Tube has of recent years been adapted to this purpose and its use is increasing owing to its unique properties for the observation of transients and for other special features (page 663).

THE INDUCTIVE RADIOGONIOMETER

Radiogoniometer for Tuned Aerials. The theory of the inductive radiogoniometer has already been described earlier in this chapter. Figs. 139 and 140 show one method of mounting the search coil for use with tuned aerials. The two sets of field coils *a a* and *b b* are broken at the centre of each winding and leads are taken to terminals for the insertion of the aerial tuning condensers. The search coil is wound on a spherical insulating former, the leads being brought out to a pair of terminals on top of the instrument. A device is fitted in this particular design to prevent the search coil making more than three complete revolutions and thus preventing undue strain being put on the flexible leads. In some designs of radiogoniometer, slip rings are fitted, allowing unlimited rotary motion of the spindle. This is a great advantage in instruments which are in constant use, but in the case of the radiogoniometer of a directional receiver in use for commercial traffic reception from one station only, the adjustments may not be altered for days at a time, and there is the possibility that a slip ring may become tarnished and exhibit the symptoms of a disconnection when it is eventually moved. Rapid rotation of the search coil will usually cure the trouble.

This type of radiogoniometer, having a loose-coupled spherical search coil, is always used with tuned aerials, and since the efficiency of the tuned aerial reception is high and the coupling of the field coils and search coil is small, there is no necessity for the use of search coil screening or a shielded transformer.

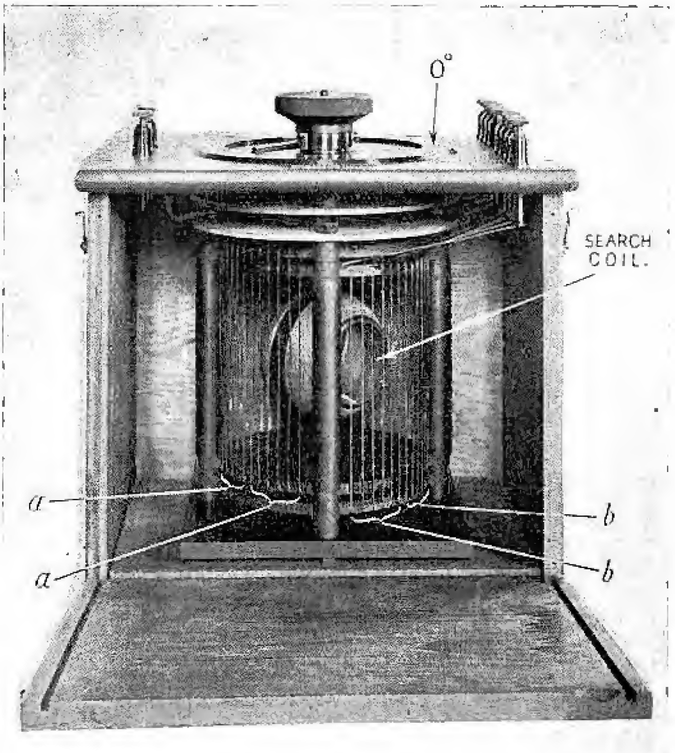


Fig. 139.—Radiogoniometer for use with Tuned Aerials.

Radiogoniometer for Aperiodic Aerials. The field coils of this instrument, shown in Fig. 141, are seen to be almost the same as in the previous case, but the search coil is cylindrical in shape and is much more tightly coupled to the field coils. This type of radiogoniometer may be used with either tuned or aperiodic aerials, but owing to its comparatively tight coupling, an inter-winding shield either in the radiogoniometer itself or in a special transformer is advisable in the former case and essential in the latter.

The instrument shown in Fig. 141 is not of recent design, but shows the relative positions of the field and search coil windings.

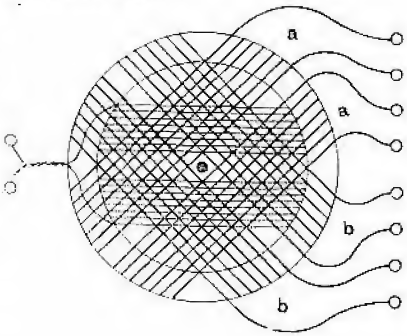


Fig. 140.—Connections of Field Coils in Radiogoniometers of Fig. 139 and Fig. 141

Coefficient of Coupling. It is customary in the case of aperiodic aerial working

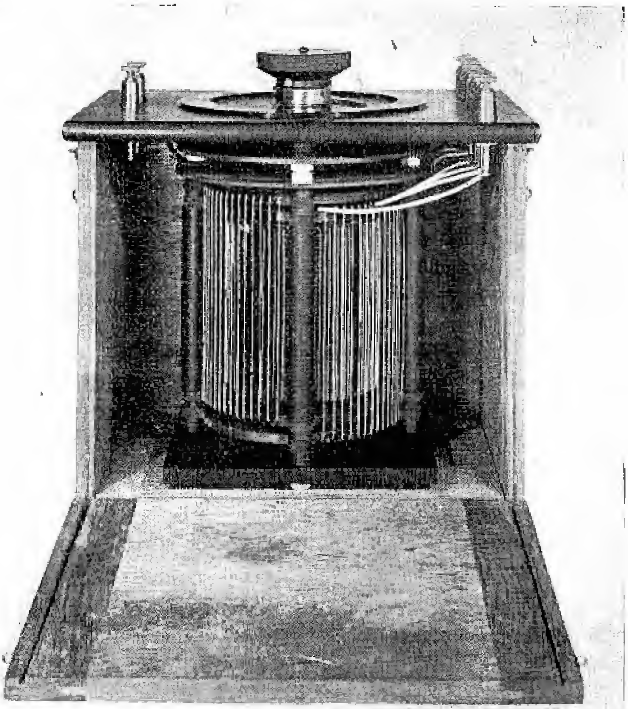


Fig. 141.—Radiogoniometer for use with Aperiodic Aerials.

to make the coefficient of coupling of the radiogoniometer not less than 50 %, and as much higher as is possible consistent with accuracy.

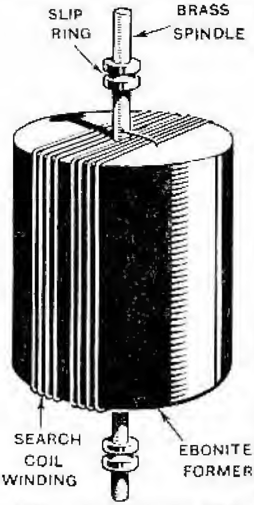


Fig. 142.—Search Coil with Slip Rings on Spindle.

Percentage Coefficient of Coupling

$$= \sqrt{\frac{M^2}{L_f\ L_s}} \times 100$$

where :

L_f = Inductance of a field coil.
L_s = Inductance of the search coil.
M = Mutual inductance between the field and search coil systems.

Inductance of Windings. It is an advantage to try to arrange that the leakage inductance of the field coil, namely

$$\sqrt{L_f L_s - M^2},$$

is approximately equal to the aerial loop inductance. The search coil inductance is governed by the frequency range to be covered by the apparatus taking into account any other coupling coils in series with the search coil.

Points in the Design of the Radiogoniometer. Those of the conditions for the accurate working of the B-T system mentioned on page 141 which depended upon the design of the radiogoniometer, may now be examined in rather greater detail.

One of the most important factors is the maintenance of electrical symmetry in the field coil circuits. These coils must be identical with regard to the number of turns, the spacing of the turns, type of wire used and the resistance and inductance. The magnetic fields produced by the field coils have to be proportional to the e.m.f.'s in the respective loops and clearly any one of the above factors can influence the strengths of the fields.

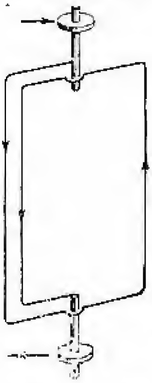


Fig. 143.—Asymmetry of Search Coil Winding due to use of "Live" Spindle.

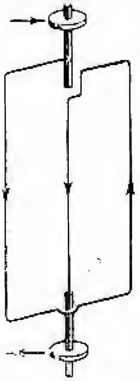


Fig. 144.—Symmetrical Search Coil Winding, using "Live" Spindle.

The field coils must have their electrical axes at right angles and must be free from mutual inductance.

The search coil must have its winding symmetrical with reference to the spindle and the field coil windings. If the spindle be made in two halves, insulated from one another at the centre, and having slip rings fitted for leading out the winding as in Fig. 142, it will normally happen that there is one more half turn on one side of the coil than on the other, as shown in Fig. 143. When the number of turns is large, the effect of this odd half turn seems to be negligible, but in low-inductance search coils with very few turns it is preferable, where extreme accuracy is required, to adopt some such scheme as in Fig. 144 in which the odd half turn is brought down the centre of the coil, preserving the symmetry of the winding.

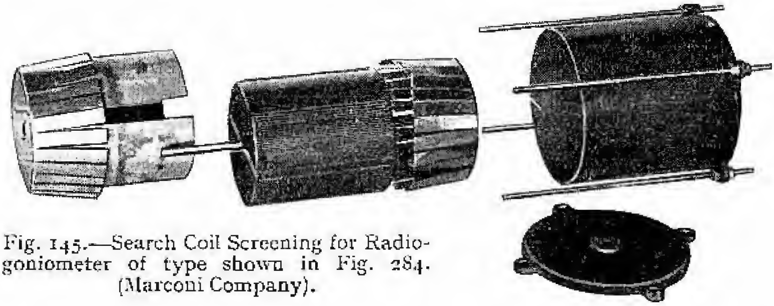


Fig. 145.—Search Coil Screening for Radiogoniometer of type shown in Fig. 284. (Marconi Company).

A more satisfactory method is to have a hollow spindle with two insulated slip rings at one end, and to bring the two ends of the windings out together as in Fig. 146. This has the advantage of allowing the spindle to be earth-connected and so reducing the possible effect of hand capacity, etc. It also ensures perfect screening of the search coil leads and, by keeping them close together, reduces the chance of pick-up or stray coupling to other parts of the circuit.

The Screened Search Coil. Fig. 145 shows the search coil components and field coil former of a radiogoniometer similar to one of the pair in Fig. 284. The search coil winding is covered by a layer of presspahn over which are placed the two copper foil shields, the method of mounting of which can be better seen in Fig. 146. Each section is connected to the spindle and thence to earth through a slip ring and the method provides a very efficient screen against vertical effect without introducing a short-circuited loop in any plane in the shield.

A further method of search coil screening is with a squirrel cage type of shield as in Fig. 147, in which wires are connected to a metal ring on the spindle at one end and to a ring of insulating material at the other end, thus again avoiding closed loops in the plane of the winding. The spacing and gauge of the wires are selected by trial and the figures given in the drawing refer to the search coil of the volume balancing radiogoniometer of T. L. Eckersley's (Marconi) Balanced Frame Short-Wave D.F. described on page 384.

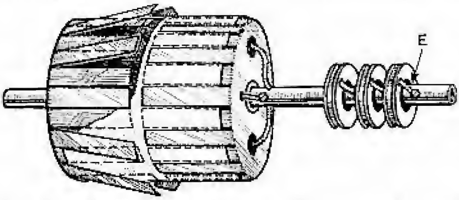


Fig. 146.—Search Coil, showing Screening Assembly.

Scale Errors. The scale of the instrument must be accurately engraved and centrally mounted, and in the case of radiogoniometers intended for important work, the scale should be metal and machine engraved. The majority of the composition scales of the type used for variable condensers, etc., are worse than useless. Amongst their more common faults are:

(1) Inaccuracy of the divisions on the scale.

(2) The scale was not mounted centrally when made so that the geometric centre of the scale is not at the intersection of the 0°–180° and the 90°–270° lines. If such a scale be used the error produced is similar to vertical, namely that the minima are not opposite one another.

(3) Many composition scales warp badly with age.

For first-order accuracy, the radiogoniometer should be considered as a precision instrument, and every possible care taken in its construction. Windings should all be run in machined slots and all preventable errors eliminated, so that, during installation of the instrument later, the practical problems of calibration, etc., may not be rendered still more difficult by the existence of an element of doubt regarding the most vital part of the receiver.

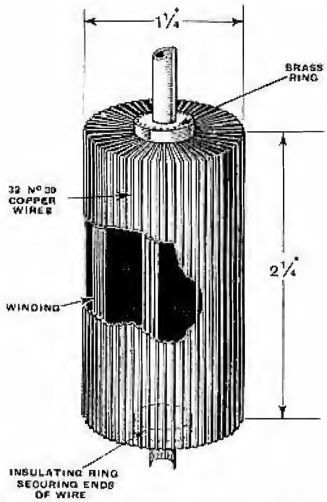


Fig. 147.—Search Coil employing Wire Cage Screen.

The error due to scale eccentricity takes the form shown in Fig. 148. In this example the points of zero error are at 30° and 210° whilst the maximum error of 2° is at 120° and 300°. This means, as shown in Fig. 149, that the centre of the scale is on the line through the 30°–210° markings, and since the readings are high between 30° and 210° the scale is eccentric towards the 30° point. The centre of the engraving is therefore at C, where the distance of C from the centre of the search coil spindle is equal to the width of 2° of scale.

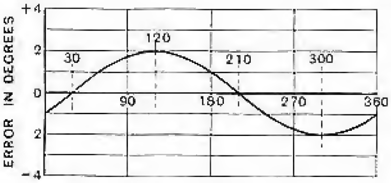


Fig. 148.—Error due to Scale Eccentricity of Fig. 149.

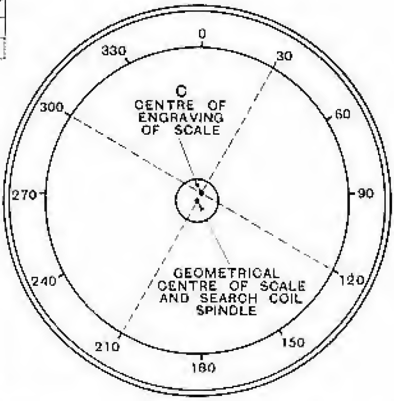

0
330
30
300
60
270
90
240
120
210
150
180
C
CENTRE OF ENGRAVING OF SCALE
GEOMETRICAL CENTRE OF SCALE AND SEARCH COIL SPINDLE

Fig. 149.—Eccentricit of Scale Engraving with Reference to Geometrical Centre of Scale.

Scale and Pointer Assemblies. Referring again to Fig. 54 (*c*), which shows the composition of the heart-shaped diagram, it will be noted that the minimum of the heart-shape is at right angles to the minima of the figure eight. Most radiogoniometers which are used for both direction finding and sense determination are, therefore, provided with two pointers at right angles. One pointer moves close to the scale and is engraved with a fine line for the accurate reading of bearings on the divided circle, whereas the other is shorter and has no definite index, being used merely for examining the two minima observed by the plain D.F. in order to decide upon the sense to be assigned to the direction of the transmitting station (see Figs. 288, 361, etc.).

In commercial ship designs, it is common to find a Dumb Compass card in the form of a movable scale that can be made to coincide with the ship's course (page 445). This may involve the use of two pointers for D.F. as in Fig. 353, in which case they are diametrically opposite.

COUPLING ERROR OF RADIOGONIOMETER

If carried too far, the tight coupling of the radiogoniometer used with aperiodic aerials may be the cause of serious errors owing to the difficulty of maintaining the true cosine law of the instrument in these circumstances. On page 139 it was pointed out that the direction of the magnetic flux inside the field coils bears the same space relationship to the coils as does the direction of the incoming wave to the two frame aerials. This is only true, however, if the two fluxes set up by the currents

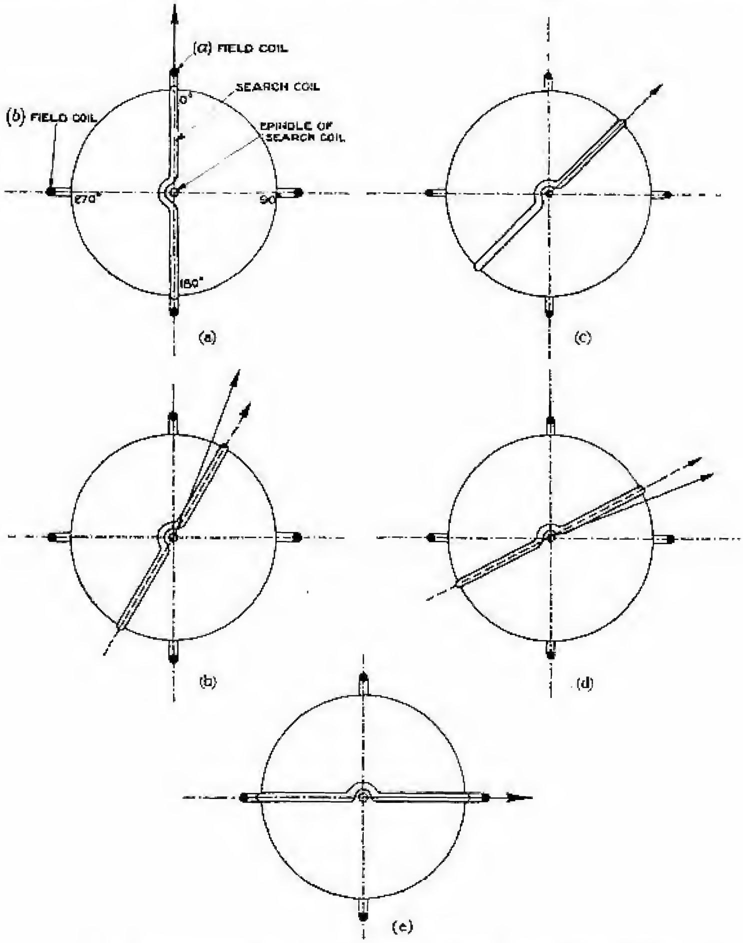


Fig. 150.—Theory of Coupling Error of Radiogoniometer.

flowing through the field coils are perfectly uniform. The intensity of a magnetic flux set up by a current in any solenoid is greatest near the conductors forming the winding and diminishes towards the centre of the coil. This change in intensity becomes more marked when the coil is not long compared with its diameter and consequently is very pronounced in the field coils of a radiogoniometer.

It has hitherto been stated that the operation of taking a bearing consists in turning the search coil to such a position that minimum signals are heard in the telephone receivers, thus indicating that the coil lies with its cylindrical axis at right angles to the resultant field. Since the resultant field corresponds in direction to the incident wave, the angular position of the search coil will be an accurate indication of that direction. What we are actually doing, however, is finding by experiment a position of the search coil such that the e.m.f.'s induced in it by the currents in the two field coils are just equal and opposite, and owing to the non-uniformity of the two fields this position may be different from that in the ideal homogeneous fields.

In Fig. 150 are shown various positions of the search coil of a tightly coupled radiogoniometer. In each case the full arrow represents the direction of the resultant field at the centre of the field coils. The field coils and search coil are assumed to have one turn only each, and the diagrams are cross sections of the windings taken perpendicular to the axis of rotation. In case (*a*) the resultant field lies in the plane of the 0°–180° field coil, *i.e.*, there is no current in that field coil and the pointer will indicate correctly. At (*b*) the resultant field lies about 20° clockwise from the 0°–180° field coil. If, however, we turn the search coil so that its plane lies along this direction, then, owing to the fact that its conductor is nearer to the 0°–180° coil than to the 90°–270° one, it will lie in a part of the field of the former coil which is relatively more intense than that of the latter, and consequently signals will be heard. In order to compensate for this non-uniformity of the fields, the coil must be turned to some position such as shown in (*b*) so that it lies further from the 0°–180° coil. This gives a plus error when signals are arriving at about 20° clockwise from the North-South aerial which is normally connected to the 0°–180° field coil. At (*c*), the resultant field lies at 45° and in this case, since the search coil, when in the plane of the resultant field, is spaced equidistant from each field coil, no error is introduced. Case (*d*) shows the resultant field about 70° from the 0°–180° coil, and since the search coil is now lying in a relatively more intense portion of the field of the 90°–270° coil, the actual minimum will be displaced anti-clockwise, giving a minus error. When the resultant field lies in the plane of the 90°–270° coil as in (*c*), no error exists, as in case (*a*).

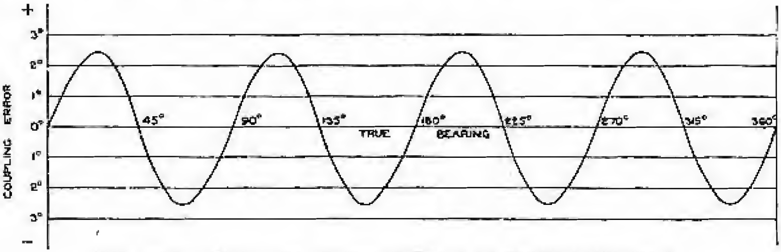


Fig. 151.—Graph of Coupling Error of Radiogoniometer.

This cycle is repeated in each quadrant and the result is an error curve as in Fig. 151, the effect being known as **Coupling Error** or **Octantal Error.** In the case of the single turn or concentrated windings considered above, the error is always positive in the first octant but, in some forms of distributed windings, the error may be negative between 0° and 45° and positive from 45° to 90°, etc.

Measurement of Mutual Inductance. A method of arriving at the coupling error of a radiogoniometer is by measuring the mutual inductance between the search coil and one of the field coils at various points on the scale, and comparing the resulting curve, when plotted, with a cosine curve. For complete accuracy the two should be identical. Actually, they rarely coincide except in a very loosely coupled instrument, in which the field coil winding is well spaced and the search coil is small and is hence moving in a relatively uniform field, or in a radiogoniometer in which the field coil, instead of being a uniformly distributed winding, is specially graded to produce sine wave coupling, as in the case of the one mentioned on page 164.

In the case of a medium- or long-wave instrument in which the maximum mutual inductance may be of the order of hundreds of microhenries, the mutual inductance may conveniently be measured with a Campbell Inductometer and below is tabulated a set of readings taken from a radiogoniometer in which there was excessive coupling error. Column 1 is the reading of the pointer, it being assumed that for 0° the search coil and the field coil are *in the same plane.* Column 2 gives the mutual inductance as measured. Column 3 is the result of making the maximum mutual inductance equal to unity and reducing the remainder of the readings in proportion. By this means the values are more easily compared with the true sine curve.

1	2	3	4	5	6	7	8	9	10	11
Scale Reading.	Mutual Inductance in μhy.	Mutual Inductance reduced to Unity Maximum.	Cosine of Scale Reading	(Col. 3)²	Sum of complementary squared Mutuals.	√Col. 6.	Percentage change in Mutual.	Quotient of complementary Mutuals = Cot θ (see below)	θ	Error of Radiogoniometer.
0°	245·8	1·0000	1·0000	1·0000	1·0000	1·0000	0·00	Infinity	0	0
5°	244·4	0·9950	0·9962	0·9900	0·9949	0·9974	0·26	14·170	4° 2′	0° 58′
10°	240·8	·9796	·9848	·9596	·9805	·9901	0·99	6·784	8° 23′	1° 37′
15°	235·2	·9571	·9659	·9160	·9652	·9824	1·76	4·316	13° 3′	1° 57′
20°	227·1	·9240	·9397	·8538	·9481	·9738	2·62	3·073	18° 2′	1° 58′
25°	216·2	·8799	·9063	·7742	·9189	·9586	4·14	2·313	23° 23′	1° 37′
30°	203·0	·8260	·8660	·6823	·8887	·9424	5·76	1·818	28° 49′	1° 11′
35°	189·1	·7695	·8192	·5922	·8707	·9331	6·70	1·458	34° 27′	0° 33′
40°	176·2	·7170	·7660	·5141	·8665	·9309	6·91	1·208	39° 38′	0° 22′
45°	161·9	·6587	·7071	·4339	·8678	·9315	6·85	1·000	45°	0°
50°	145·9	·5937	·6428	·3524	·8665	·9309	6·91	1·208	39° 38′	0° 22′
55°	129·7	·5278	·5736	·2785	·8707	·9331	6·70	1·458	34° 27′	0° 33′
60°	111·7	·4543	·5000	·2064	·8887	·9424	5·76	1·818	28° 49′	1° 11′
65°	93·5	·3804	·4226	·1447	·9189	·9586	4·14	2·313	23° 23′	1° 37′
70°	73·9	·3007	·3420	·0943	·9481	·9738	2·62	3·073	18° 2′	1° 58′
75°	54·5	·2218	·2588	·0192	·9652	·9824	1·76	4·316	13° 3′	1° 57′
80°	35·5	·1444	·1736	·0209	·9805	·9901	0·99	6·784	8° 23′	1° 37′
85°	17·3	·0702	·0872	·0049	·9949	·9974	0·26	14·170	4° 2′	0° 58′
90°	0	·0000	·0000	·0000	1·0000	1·0000	0·00	Infinity	0	0

Column 9 is obtained in the following way :

$$\frac{\text{Mutual Inductance for } 0^\circ \text{ Scale Reading}}{\text{Mutual Inductance for } 90^\circ \text{ Scale Reading}} = \frac{245{\cdot}8}{0} = \text{Inf.}$$

$$\frac{\text{Mutual for } 5^\circ}{\text{Mutual for } 85^\circ} = \frac{244{\cdot}4}{17{\cdot}3} = 14{\cdot}17$$

$$\frac{\text{Mutual for } 10^\circ}{\text{Mutual for } 80^\circ} = \frac{240{\cdot}8}{35{\cdot}5} = 6{\cdot}784$$

Etc.

Variable Total Mutual Inductance. When the plane of the search coil makes an angle of, say, 10° with the plane of one field coil, the mutual inductance between these two should be proportional to cosine 10°, which is 0·9848 of the maximum value. In this position the search coil is making an angle of 80° with the other field coil so that the mutual inductance between them should be proportional to cos 80°, which is 0·1736 of the maximum. The total mutual inductance between the search coil and both aerial circuits is the square root of the sum of the squares of these two components, namely:

$$\sqrt{0{\cdot}9848^2 + 0{\cdot}1736^2} = \sqrt{0{\cdot}9699 + 0{\cdot}0301} = 1$$

The total mutual inductance is thus a constant amount so long as the mutual inductance between the search coil and individual field coils follows the cosine law. In Column 5 the actual test values of the mutual inductance have been squared, and in Column 6 the complementary squared values

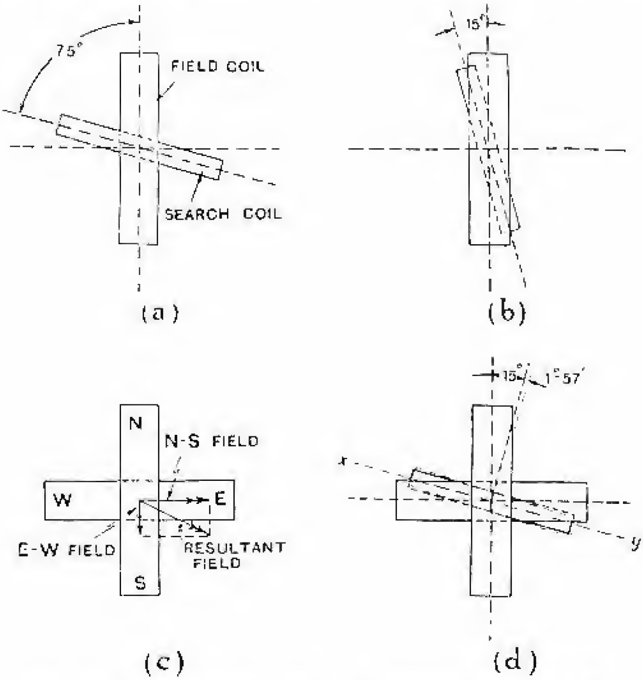


Fig. 152.—Calculation of Coupling Error from Measured Mutual Inductance of Search Coil and Field Coils.

have been added together, that is to say, the square of the mutual for 5° added to the square of the mutual for 85°, and so on. Column 7 is the square root of Column 6. Column 8 is the percentage change in total mutual inductance as the search coil is rotated from 0° to 90°. Up to 45° the change will increase and will then decrease again to zero at 90°, where there is linkage with one field coil only.

This change in total mutual inductance between the search coil and aerial circuits is an important factor, since it may cause mutual interference in twin or multi-channel stations by altering the tuning of the search coil circuit of a receiver when the radiogoniometer of a second receiver, which is tuned to the same wave length, is rotated. Yet another ill effect is in the case of a D.F. or directional receiver employing a high-frequency amplifier which is in an unstable condition due to reaction. The comparatively slight change in tuning of the high frequency circuits may produce large changes in signal strength, giving the effect of four maxima and four minima during one revolution of the search coil.

Coupling Error Calculated from Mutual Inductance. From the figures in the table it is now a simple matter to determine what the coupling error is for any position of the search coil. We know that for complete accuracy when the pointer is at, say 15°, the ratio of the two component fields linking the search coil should be $\frac{\cos 15^\circ}{\cos 75^\circ}$ which is cot 15°. Actually the fields linking the search coil are in the ratio $\frac{\text{Mutual Inductance for } 15^\circ}{\text{Mutual Inductance for } 75^\circ}$ and this, from the test results, is equal to $\frac{235\cdot2}{54\cdot5} = 4\cdot316$ which is found to be cot 13° 3′. The ratio is thus too large, owing to the fact that when the search coil is situated with respect to a field coil as shown in Fig. 152 (*a*), the mutual inductance is too small, whilst when it is in the position shown in Fig. 152 (*b*), the mutual although still too small, is proportionately more correct in value than in Fig. 152 (*a*). If, therefore, the currents in the N-S and E-W field coils are in the correct ratio, namely, $\frac{\cos 15^\circ}{\cos 75^\circ} = \frac{0\cdot9659}{0\cdot2588} = 3\cdot732$, as they would be if due to e.m.f.'s in the aerials produced by a signal having a 15° angle of incidence, the resultant field will be as in Fig. 152 (*c*). The search coil, if placed in the position in which it should have no linkage with this resultant field, as at $x\,y$ in Fig. 152 (*d*), will now be too loosely coupled with the

N-S field coil and relatively too tightly coupled with the E-W field coil, and will have to be rotated clockwise through 1° 57′, to give a zero signal balance. The apparent error will thus be + 1° 57′.

These ratios of complementary mutual inductances are given in Column 9, and the corresponding angles in Column 10. The last column gives the errors, and these have been plotted in Fig. 153. The maximum error is thus 2° at 18° on the scale, and the cycle will be repeated, positive and negative in alternate octants, as already mentioned.

Coupling Error Calculated from Attenuator Readings. A method sometimes used, and one that is in some respect preferable to the above one, is to employ the search coil and one field coil of the radiogoniometer as a coupling to an amplifier in the output of which is an indicating meter with an attenuator. By this means the law of the instrument can be obtained and compared to a cosine law in a simple manner. Since, however, 1 db. represents a voltage or current change of 12% it becomes necessary to have an attenuator capable of measuring to centibels and with the high maximum value of attenuation required to discriminate between the coupling at the maximum and at very low values.

To Check the Accuracy of a Radiogoniometer Against a Standard. An alternative method of checking a radiogoniometer for coupling error is to connect its field coil terminals to those of a standard instrument and then, exciting the search coil of the standard at a radio frequency within the band over which the apparatus is to work, to check the readings of the pointers for the positions of minimum signals over the complete scale. A suitable receiver and amplifier is required and both radiogoniometers must be adequately screened, separated far enough to avoid inductive coupling and connected by screened leads. If the apparatus is for use on long waves a check on audio frequency, using a strong input signal and telephones direct in the No. 2 search coil circuit, gives a close approximation to the correct result but a radio frequency check is preferable and is essential on short wave apparatus. Assuming that the two radiogoniometers have their pointers set in the same positions relative to their search coils, it will be found on connecting the field coils as in Fig. 154 (*a*), and setting the pointer of the standard to 0°, that the other pointer will read 90° or 270° for the position of minimum.

The reason for this is that if the search coil of the standard is in the plane of the E-W field coil, then there will be maximum current in this circuit and none in the N-S coil so that to obtain a minimum in the radiogoniometer under test, its search coil must be set at right angles to the E-W coil.

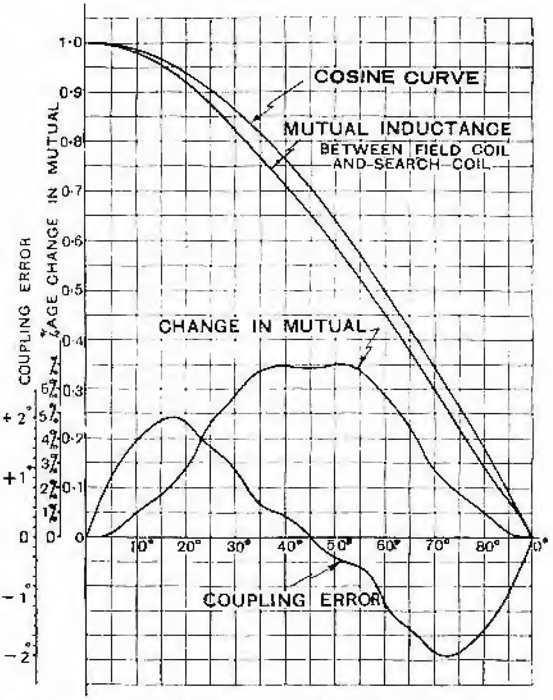


Fig. 153.—Graph of Measured Mutual Inductance and Calculated Coupling Error.

If, for any reason, it is desired to make the minimum of the radiogoniometer under test read the same as the pointer of the standard, it may be done by interchanging the field coil leads and reversing one pair as shown in Fig. 154 (*b*). This is worth considering for a moment, since the method of investigating the effects of cross connecting field coils in this manner is also applicable to the diagnosing of certain errors of a similar nature which are mentioned on page 355.

Assume that the pointers and search coils are in each case in the same plane, and that the 0°-180° line of the scale is in the plane of the N-S field coil. Then, if the standard pointer be at, say, 20°, the search coil will be rotated 20° clockwise from the

N-S field coil and there will be a large current in the N-S coil and a small one in the E-W coil. If a convention be adopted for the relation between the instantaneous direction of the current in a field coil and the direction of the magnetic flux, we can examine the directions of the currents and resultant magnetic flux in the radiogoniometer under test and so determine what will be the position of the pointer. Let us assume that a flux, threading the N-S field coil in the direction W to E will result in an e.m.f. and a current flowing from N to S in the N-S field coil.

This is shown in Fig. 154 (*c*), where the heavily barbed arrows represent the direction of the current and the lighter arrows, the flux. Conversely, a current flowing, at any instant, in the N-S field coil, from the S to the N terminals, will produce a flux along the axis of the coil *in the direction of E* as in Fig. 154 (*d*).

Referring to Fig. 154 (*e*), the flux of the standard search coil is shown along its axis and is resolved into rectangular components F_{ns} and F_{ew} threading the two field coils. Following the convention mentioned above, these fluxes will produce field coil currents I_{ns} and I_{ew} in the direction shown by the arrows in the Figure. Coming to the radiogoniometer under test (Fig. 154 (*f*)), the larger current from the N-S field coil of the standard now flows in the E-W coil and the smaller current in the N-S coil, and these produce fluxes and currents as shown. It will now be seen that the resultant flux makes an angle of 20° with the N-S field coil and for the condition of minimum signals, the plane of the search coil and hence the pointer must be in this direction.

If the field coil connections are simply interchanged without reversing one of the pairs it will be found that a minimum is obtained when the two pointers are set at 0°, but that when the standard is rotated clockwise through 20°, the other has to be rotated 20° *anti*-clockwise in order to maintain the minimum. Compare these results with the notes on page 357 regarding the errors brought about due to accidental cross connection of aerial and field coil leads.

Radiogoniometer for Use as a Standard. If the back-to-back method is to be adopted for test-room use, it is useful to have as a standard, a radiogoniometer sufficiently free from coupling and scale errors to have an accuracy of, say, one tenth of a degree at all points on the scale. This is not easy to attain, but the loose-coupled instrument shown in Fig. 139 has a maximum coupling error of about a quarter of a degree, and by paying special attention to precision in the construction of the mechanical parts, the mounting of the scale, etc., the accuracy comes within the limits normally required in commercial D.F. apparatus.

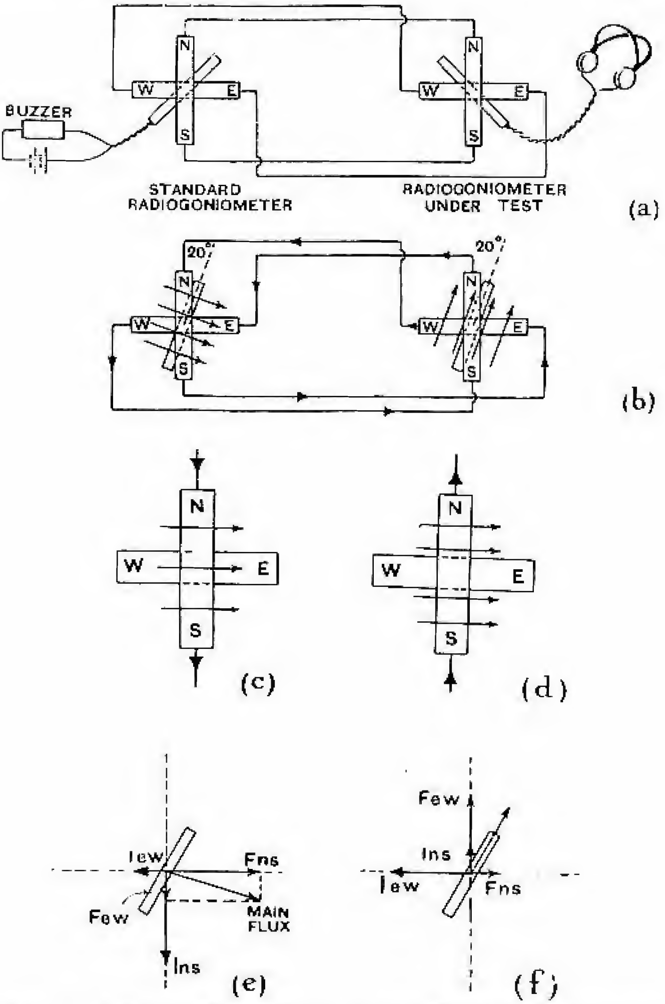


Fig. 154.—" Back to Back " Comparison of Two Radiogoniometers.

The method described below, however, in which a special design of field coil is used to reduce the coupling error to a negligible amount, even with a tightly coupled radiogoniometer, is of particular interest.

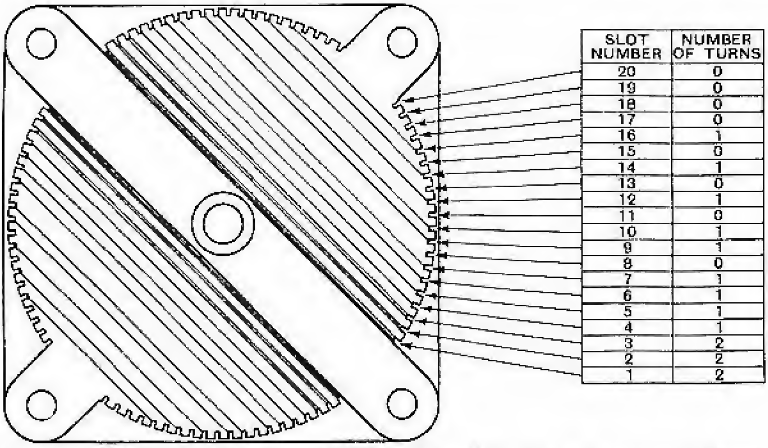
Error Reduction by Special Field Coil Design. Arising out of an investigation of octantal error, carried out by Messrs. Standard Telephones and Cables Ltd., that Company has produced a radiogoniometer that is substantially free from error, the principle of the method employed being as follows:

An analysis of the curves for the mutual inductance between field and search coils in the case of windings that are uniformly distributed over about two-thirds of the periphery of cylindrical formers, showed that the law connecting the e.m.f. in the search coil circuit with its angular position could be represented closely by the expression:

$$E = A_1 \sin \theta + A_3 \sin 3\theta$$

where E = the e.m.f. in the search coil circuit
θ = angular displacement of the search coil
and A_1 and A_3 are constants.

In this expression it will be seen that a third-harmonic term is present, but terms above the third harmonic were found to be negligible, whilst a consideration of the symmetry of the coils shows that even harmonics cannot exist.



SLOT NUMBER	NUMBER OF TURNS
20	0
19	0
18	0
17	0
16	1
15	0
14	1
13	0
12	1
11	0
10	1
9	1
8	0
7	1
6	1
5	1
4	1
3	2
2	2
1	2

Fig. 155.—Field Coil Winding of "Error-Free" Radiogoniometer of Messrs. Standard Telephones and Cables Ltd.

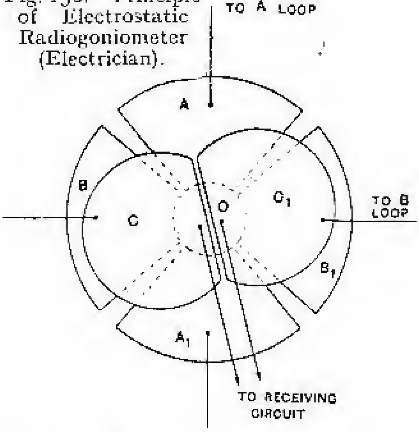
Suppose now that a second winding be put on the search coil former, identical with the first, but displaced at an angle of 60° from it, and that the two windings are connected in series; the resulting e.m.f., with the same field coil current, would be:

$$E' = A_1 [\sin \theta + \sin (\theta + 60^\circ)] + A_3 [\sin 3\theta + \sin 3 (\theta + 60^\circ)]$$
$$= A_1 \sqrt{3} \sin (\theta + 30^\circ)$$

In this expression, the third-harmonic term does not appear, indicating that the error is eliminated.

Except for the constants, the coupling law is the same whether the search coil e.m.f. is being considered for a given current flowing in the field coils, or vice versa, so that the addition of a second winding to the field coil will have an exactly similar result. This somewhat simplifies the construction, and a further modification is that of substituting for the double winding, a single equivalent winding, in which the distribution of the turns is arranged to produce a magnetic field identical with that which would result from the double winding.

Fig. 156.—Principle of Electrostatic Radiogoniometer (Electrician).



The data for this equivalent winding is shown in Fig. 155, where the slots are seen to be evenly spaced, as in the normal field coil winding, but in this case 8 of the 20 slots are empty, 9 have a single turn and 3 have two turns. With this arrangement a coefficient of coupling of 75% can be obtained with an octantal error of one-third or one-quarter of a degree.

In the 1927 edition of this book, a similar method for reducing coupling error was described in which two windings were used at an angle of about 45° and connected in series. In this case the existence of the third-harmonic term in the coupling and the necessity for a 60° disposition of the windings was not an essential part of the method, which was found to reduce the coupling error by about 50%.

THE ELECTROSTATIC RADIOGONIOMETER

In addition to the inductive or magnetic form of radiogoniometer already described, there is also a form of capacity radiogoniometer in which the field coils and search coil are replaced by the fixed and movable vanes of a special form of electrometer.

Fig. 156 shows the general principle of the instrument in which A A_1 are one pair of fixed plates, and B B_1 the other pair, connected respectively to the two B-T loops. C C_1 are the two moving plates which are insulated from one another and rotate about the axis O. The detector is connected across these moving plates which are made in a special shape so that the instrument shall have the necessary cosine law enabling it to be used in the same way as the inductive radiogoniometer. The arrangement of the plates may take several forms, two of which are shown in Fig. 157 and Fig. 158. In the former, each fixed vane is seen to be a quadrant of a circle, whilst in Fig. 158 each plate is approximately a semicircle, so that it becomes necessary to arrange the two sets of fixed plates in different planes, with the moving plates between them, as shown on the left.

As in the inductive radiogoniometer, it is important to maintain a constant overall coupling between the moving and fixed systems, and the chief virtue of the arrangement of Fig. 158 is that, provided the tuning condenser connected across the moving vanes has a certain minimum capacity, the loops can be tuned merely by added inductance as shown and the instrument works satisfactorily.

If the quadrant plates be used as in Fig. 157, then it is found that the capacity between the fixed and moving systems is subject to variations which prevent the proper working of the instrument, unless condensers of a certain minimum capacity are connected across the pairs of fixed plates in addition to the moving plates.

The Compagnie Générale de Télégraphie, of Paris, have constructed radiogoniometers which employed the circuit of Fig. 157 and had a range of wave length of 200 to 2,000 metres, but they have never come into common use as direction finders.

Details of the theory of the electrostatic radiogoniometer, and also the various forms which the instrument may take, are given in an article by E. Bellini (1914) from which the above abstract has been taken.

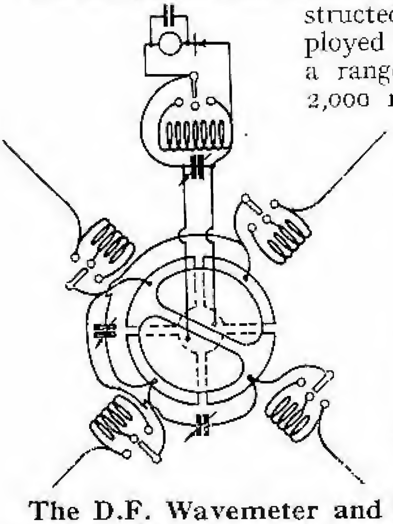


Fig. 157.—Electrostatic Radiogoniometer with Quadrantal Plates (Electrician).

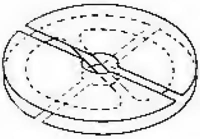
The D.F. Wavemeter and Tuning Buzzer. This apparatus, which is only used in connection with the tuned aerial circuit, is shown in Fig. 159. It consists of a box in the centre of which a winding on a spherical former is arranged so that it may be rotated about a vertical axis. At the corners of the box, four vertical insulating tubes are fixed through which the aerial leads are taken at some point between the lead-in and the radiogoniometer. This type of construction is adopted in preference to fixed windings and terminals as it reduces the number of screwed connections in the aerial circuits, an important point in the case of tuned B-T loops owing to the risk of added resistance. Each aerial lead makes half a complete turn round the box, enabling the aerials to be coupled to the buzzer circuit. This geometrical arrangement of the aerial leads complies with the requirements of the tuned aerial system, namely :

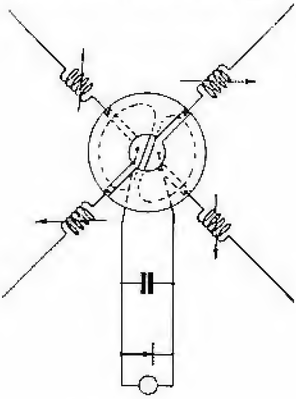
Symmetry of aerials.

Equal length of leads and hence equal resistances.

Absence of mutual inductance between aerials (except by means of the spherical wave meter coil).

Fig. 158.—Electrostatic Radiogoniometer with Semicircular Plates (Electrician).





The moving coil, together with a variable condenser, forms an oscillatory circuit which is excited by means of a battery and high-note buzzer, the circuit being calibrated over the range of wave lengths on which the D.F. is intended to operate.

An important detail is that the buzzer switch is placed in the oscillatory circuit and not in the battery lead, so that during the reception of outside signals the moving coil is disconnected and does not couple the aerials.

THE USE OF TRANSMISSION LINES WITH B-T AERIALS

The necessity sometimes arises for separating the aerial site and the receiving building by a distance of several hundred metres, owing to the advantage of concentrating the D.F.

receiver along with other receiving and transmitting controls, whilst retaining an open site for the aerials.

The use of long connecting leads between aerial loop and radiogoniometer field coil makes it impracticable to use a simple connection in which the leads are part of the oscillatory aerial circuit, and an alternative method of conveying the aerial energy is adopted, namely that of the **transmission line** or **feeder.** For a proper understanding of this mode of conveying energy at radio frequencies, a more extensive knowledge of mathematics is required than is assumed in this book. The interested reader who is familiar with vector algebra and simple differential calculus must therefore be

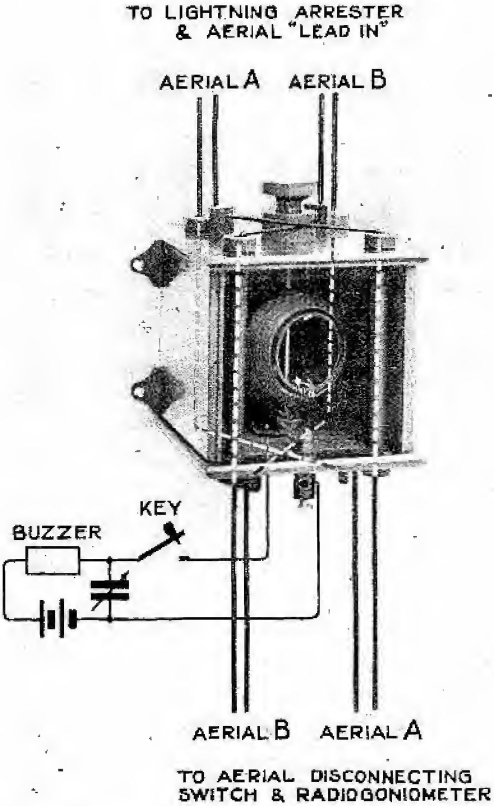


Fig. 159.—D.F. Wavemeter and Tuning Buzzer.
(See footnote on page 141).

referred to other text books on wireless telegraphy, as for instance (3616), in which the subject is dealt with at some length.

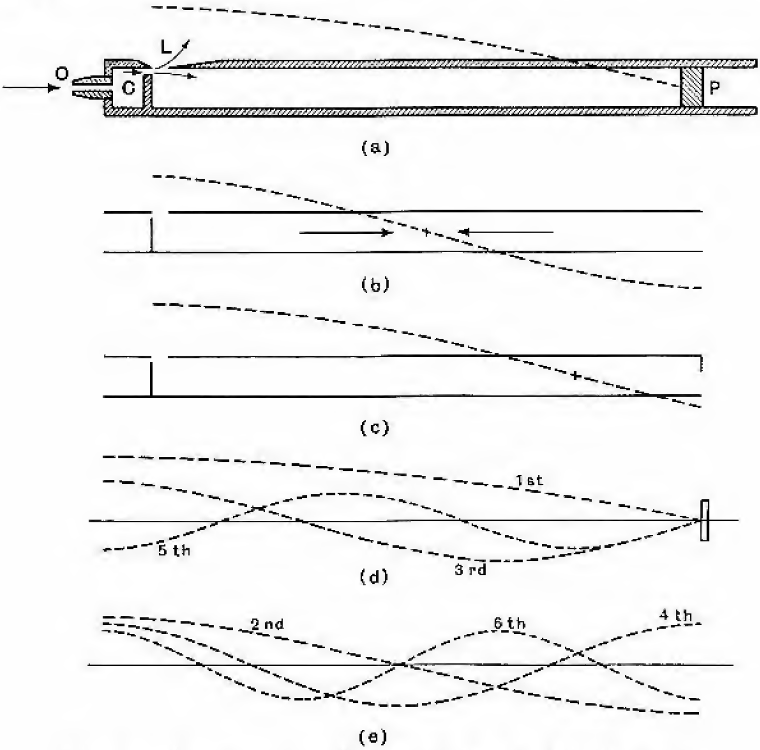


Fig. 160.—Fundamental and Harmonic Modes of Air Vibration in Open and Closed Organ Pipes.

An appreciation of the fundamental difference between the use of conductors as parts of oscillatory circuits and their use for guiding electromagnetic wave motion may, however, be gained by examination of the analogy that exists between the wave in a transmission line and the behaviour of an air pressure wave in an organ pipe.

The Closed Organ Pipe. In the organ pipe, shown in Fig. 160 (*a*), air enters under pressure at O and impinges, as shown by the arrows, on the lip L, part of the air passing outwards and part to form a pressure wave that travels up the inside of the pipe. At the end is a plug, and here reflection occurs, and a wave travels down the pipe to meet air still being forced in. The result is that the entering air now all goes out of the mouth of the pipe, this being the easier path, continuing to do so after the pressure wave has been expended, so that a partial vacuum results. The low pressure inside and near to the mouth of the pipe now causes air to pass into the pipe again at the lip L, continuing to do so until another pressure wave is formed and so on, thus producing a resonant air movement up and down the pipe.

If a dotted line be drawn to represent air motion (as a line is sometimes drawn to represent the current distribution in an aerial), it will appear as shown, the plug P being a point of maximum pressure change and zero motion, otherwise a **node,** whilst the open mouth is a point of almost zero pressure change and maximum motion, or an **antinode.** The method of oscillation of the air is thus such that the wave length is four times the length of the pipe

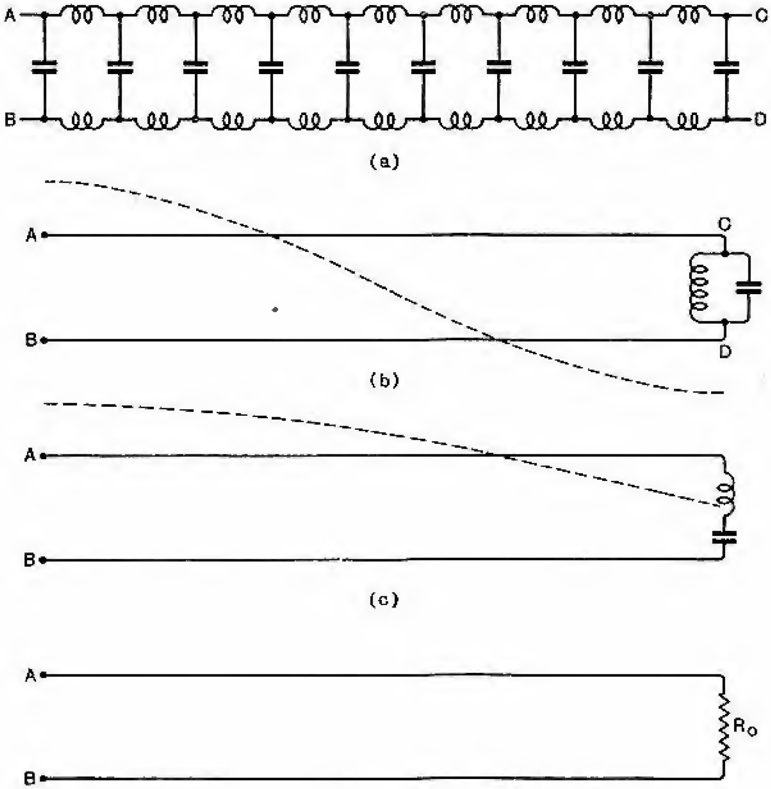
The Open Organ Pipe. If now the end of the pipe be open as in Fig. 100 (*b*) the open end cannot be a point of maximum pressure change and it becomes an antinode, so that when the air column is in oscillation, waves of pressure travel towards and away from the centre. The line representing air motion will now indicate zero movement at the centre with maximum movement at the ends, and the wave length is twice that of the pipe.

Tuning the Pipes. By moving the plug P up and down the closed pipe, the wave length will be increased or reduced, and the pitch of the note correspondingly lowered or raised. Similarly, if the end of the open pipe be slightly constricted by means of a metal plate, the air movement will be hampered and the antinode that was previously at the centre will move up as in Fig. 160 (*c*) with an increase in wave length.

Harmonics. In addition to the fundamental wave length of the oscillation shown in the diagram, harmonic oscillations may also be produced at the same time and give the characteristic tone of the organ. From the diagram of Fig. 160 (*d*) and (*e*) it will be clear that odd harmonics are produced in the closed pipe and even harmonics in the open one.

Non-Sounding Organ Pipe. Now suppose the pipe to have a plug of cotton wool inserted in place of the solid plug P, the consistency of the plug being such that the air is neither able to move rapidly enough through it for the end to be an antinode, nor is the plug sufficiently solid to provide any reflection of a pressure wave. In these circumstances there is nothing but a steady flow of air in the pipe and the pressure is dissipated in the soft plug with no oscillatory motion and no sound.

The Resonant Transmission Line or Feeder. In its simplest form, neglecting resistance and leakage, the twin wire transmission line may be drawn as in Fig. 161 (*a*), where the wires have been divided into sections, and the distributed inductance and capacity shown as small coils and condensers. If now a potential be suddenly applied across the points AB at one end of the feeder, the first condenser will be charged and will discharge through the first pair of coils, and charge the second condenser. The e.m.f. due to the collapse of the magnetic field in the coils will assist the charging of the second condenser and so on. A wave will thus travel along the lines at approximately the speed of an electromagnetic wave in air and the condition that there shall be an even flow of energy



(a)

(b)

(c)

(d)

Fig. 161.—The Twin-Wire Transmission Line or Feeder.

is that the rate of discharge of each small condenser shall be exactly equal to the rate at which energy is fed to it. If energy were fed too quickly or too slowly to any section, there would be the equivalent of a charging up positively or negatively of the condensers and these, on discharging, would start a new wave along the feeder.

Such a charge may occur due to a change in the electrical constants of the feeder and obviously occurs at the open end of the line CD, where the " last condenser " has no means of discharging other than by starting a new wave in the reverse direction.

If the potential is being applied to AB from a circuit of high impedance, then, when the reflected wave returns to AB, there will be a second reflection, and provided that the applied e.m.f. be an alternating one with periodic time equal to that taken by the wave to travel up and down the line, a resonant condition occurs, the frequency of which is fixed by the length of the line.

Since voltage antinodes occur at each end of the line, the wave length is thus twice the equivalent length of the line, and the arrangement is analogous to the oscillation of air in an organ pipe with open end.

If now the impedance at the front end of the line be Z_1, and the distant end of the line be attached to, say, a portion of an oscillatory circuit which offers an impedance Z_2, then the periodicity of the complete system is fixed by the length of the line and the two impedances, just as the periodicity of the open organ pipe could be changed by constricting the end of the pipe. By making Z_1 variable, it thus becomes possible to use this as a method of remote control of the tuning of an oscillatory circuit.

Resonant Line with High Impedance Termination. In Fig. 161 (*b*) there is connected across the distant end of the line CD a parallel tuned circuit the frequency of which is that of the line system, the impedance of such a circuit being very high and giving the effect of an almost open circuit condition. The effect of such a termination upon the line is small and the natural period remains that of an open-ended line with an antinode of voltage at CD.

Resonant Line with Low Impedance Termination. If a series resonant circuit be connected across CD, as in Fig. 161 (*c*), this becomes a virtual short circuit to the end of the line and a voltage node occurs, the case being equivalent to the closed organ pipe and, assuming a high impedance at the input end, the wave length of the system is four times the length of the feeder.

The Surge Impedance Terminated Line. It was noted above that the cause of the reflections in a feeder was the inability of the charges on the imaginary small condensers to be dissipated at the same rate as the energy was fed to them. If, instead of a resonant or reactive circuit, there be connected across the terminal points CD, a resistance of such value that the " last condenser " discharges through it at the same speed at which it is being charged, then no reflection will occur and the line ceases to be resonant. Fig. 161 (*d*).

The value of the resistance to satisfy this condition is known as the **surge impedance** or R_0 of the line.

This is seen to be analogous to the organ pipe with the cotton wool plug, and there is now a steady flow of electromagnetic energy along the line, the length of which has no effect beyond that of attenuation.

It will be clear that, for power transmission, the pure resistance load must be replaced by a useful load that offers a similar impedance to the line. Lines terminated in this way are therefore not used for transmission, but have a useful application in receiving aerials, since receiving apparatus with high input impedance and requiring diminutive input power may be connected in parallel with R_0 without affecting the termination. An example of such apparatus is the valve amplifier, in which case the potential changes across R_0 are applied to the grid of a valve and losses are made up by amplification.

Stationary or Standing Waves. When a feeder is terminated by an impedance other than the surge impedance, the reflected waves that travel back to the source may combine with the forward ones to form stationary waves, an example of which are the well-known loops produced in a rope when one end is attached to a solid support and the free end is given a rapid up and down motion. These stationary waves in a feeder are undesirable, because, when there is also reflection from the input end of the line, and particularly if the length of the line is a critical value, the current antinodes will build up, with considerable C^2R losses, whilst in transmitting feeders the voltage antinodes may cause breakdown due to flash-over.

Matching Transformers. For the termination of a feeder other than by the use of a resistance equal to R_0, a transformer may be used with a transformation ratio such that whether the impedance presented by the apparatus is greater or less than R_0, the line " looks into " an impedance of R_0 and no reflections occur. Such a transformer is always used in power transmission lines at radio frequencies, and examples of its use for reception are given later.

Types of Feeder. The twin wire transmission line so far mentioned may be either suspended in air, with suitable spacing and supporting insulators, or paper wrapped, copper screened and made up into a single or multi-pair cable. In the latter case there is the advantage of shielding from external pick-up or "cross-talk" and if suitably armoured the cable may be buried.

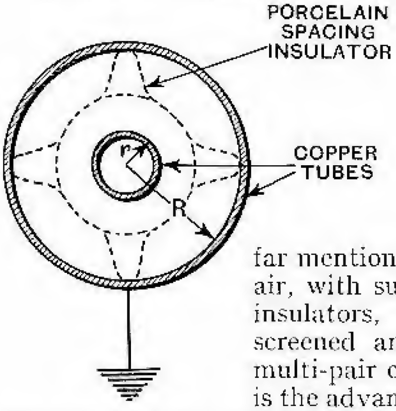


Fig. 162.—The Concentric Tube Transmission Line or Feeder.

The surge impedance of the twin wire feeder decreases with increase of the wire gauge and reduction of spacing of the wires. It varies in practice between 650 and 400 Ohms in the case of open wires, low impedances of 150 Ohms being used for special purposes. Cable pairs have a lower R_0 of the order of 100 to 60 Ohms, and the use of these for D.F. is mentioned later.

A second type is the **co-axial** or **concentric feeder** as illustrated in Fig. 162, in which the outer tube is earthed and the wave travels in the annular space between the outer tube and the inner conductor. Such feeders are made of concentric copper tubes with overall diameters of 4 or 5 inches for transmission purposes and, in various forms, down to less than an inch in overall diameter for reception, an example being given in Fig. 269.

The ratio of the inner radius of the outer tube R, to the radius of the inner conductor r in Fig. 162, governs the R_0 of a co-axial feeder, which is usually fixed at 75 Ohms.

Methods of calculating the R_0 and losses of both types of feeder will be found in (3616).

Test for Feeder Balance. When using transmission lines for connection between B-T aerials and a radiogoniometer, it is essential that they should have equal attenuation at the working frequency range, and equal electrical length. By this last expression is meant that the time taken for the wave to travel along each pair should be identical, so that the phases of the output e.m.f.'s should bear the same relations to one another as did the input e.m.f.'s, so avoiding a rotating field.

The equality of the pairs in a multicore cable may be checked by the use of a radiogoniometer. Two pairs are chosen and paralleled at one end, a radio frequency generator being used to induce a signal of the desired radio frequency. The surge impedance of the feeder being known, say 60 Ohms, the two in parallel will offer an impedance of 30 Ohms, and the generator must be matched to this value. The distant ends of each pair are connected to the field coils of a radiogoniometer, a resistance equal to R_0 being used for terminating, which is in order since the reactance of the coil will be large compared to 60 Ohms. The search coil is taken to a suitable receiver, screening of the leads and apparatus being carefully observed.

If now the cable pairs are exactly similar with regard to attenuation and phase rotation, a perfectly crisp minimum will be obtained at one of the 45° positions on the scale—the radiogoniometer having been previously checked to make sure that it is accurate. A crisp displaced zero indicates unequal attenuation, whilst a blurred zero at 45° shows equal attenuation but unequal phase rotation and there may be a combination of both effects.

It may be noted that the displacement of the zero from the 45° position will be a measure of the error to be expected if the two pairs be used in a D.F. installation, when taking a bearing of a transmitter lying midway between the planes of the two loops. Signals arriving in line with one loop will not have any error produced by this particular fault. See (3717) for further details of the testing of feeders.

CIRCUIT ARRANGEMENT USING TRANSMISSION LINES

The circuit of a B-T system with long transmission lines between loops and radiogoniometer is shown in Fig. 163 in which four cable pairs are represented by the dotted lines. T_1 to T_6 are capacity shielded matching transformers, the mid-points of the primaries of T_1 and T_2 being connected through the primary of T_3 to earth, to provide open aerial e.m.f. for sense determination as in Fig. 137.

The sense pair of transmission lines are terminated by T_6 in the same way as the other two lines, but the secondary winding is designed to include a 5,000 Ohm resistance R and a shunt circuit through C and the T_7 primary, to couple the open aerial e.m.f. to the tuned search coil circuit.

The application of this circuit is mentioned again on page 363 in connection with its use at the Niton coast D.F. station of the British Post Office, examples being given in Fig. 298 of the marked improvement in accuracy obtained by the removal of the B-T loops from the W/T station to an open cliff site.

MULTI-CHANNEL RECEPTION WITH BELLINI-TOSI AERIALS

It is not unusual in directional receiving stations which employ the B-T system, to connect more than one radiogoniometer to the aerial system, thus enabling a number of commercial traffic services to be handled on various wave lengths without the expense of duplicating mast and aerial systems. When the wave lengths are large, say 10,000 m. and upwards, this is a great saving, as the aerials required are generally extensive.

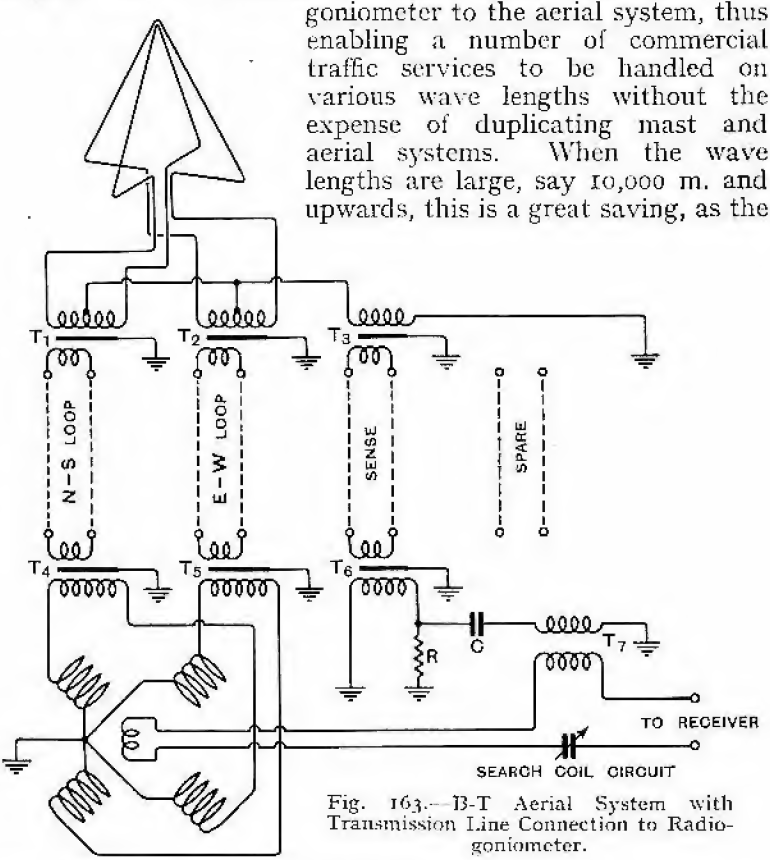


Fig. 163.—B-T Aerial System with Transmission Line Connection to Radiogoniometer.

In the case of actual D.F. stations, the use of such multichannel working is uncommon, but twin-channel working has been successfully used. In certain circumstances it may clearly be an advantage to be able, at one central receiving station, to have two direction finders working simultaneously or two directional receivers which, by means of suitable polar diagrams of reception, can take messages from or take bearings of two transmitters simultaneously. The B-T system lends itself readily to multi-channel working of this nature.

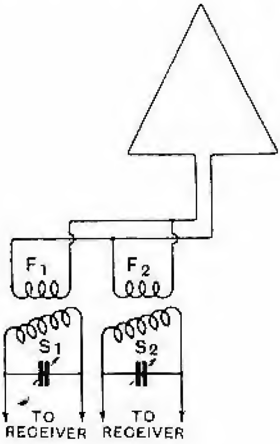


Fig. 164.—Two Radiogoniometers Connected to a B-T Aerial without Anti-Coupling.

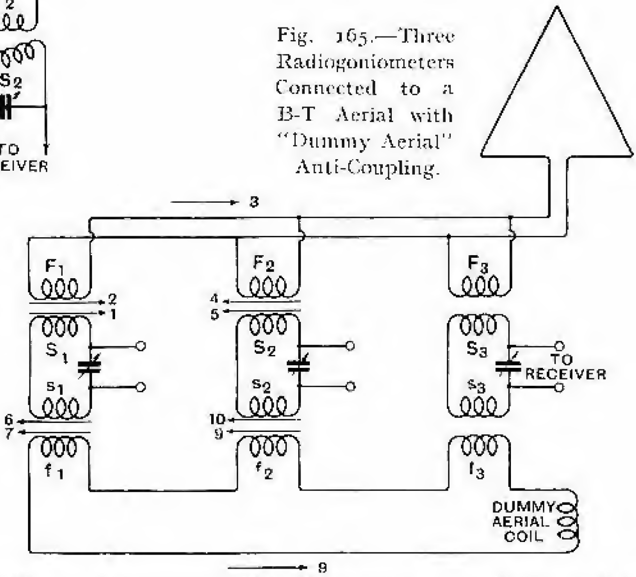


Fig. 165.—Three Radiogoniometers Connected to a B-T Aerial with "Dummy Aerial" Anti-Coupling.

In Fig. 164, F_1 is the field coil of a radiogoniometer, and S_1 a search coil winding with tuning condenser and leads to an associated receiver. The field coil is shown connected to one loop of a B-T aerial system, in parallel with which is the field coil F_2 of a second radiogoniometer. The other two field coils are similarly connected in parallel across the second loop aerial but are not illustrated. It is easy to see that these two radiogoniometers cannot be worked independently, for any current in the search coil S_1 due to a signal will result in interference in S_2 owing to the tight coupling via F_1 and F_2. Similarly any signal in S_2 will interfere with the first receiver. Only when the wave lengths of the two signals are widely different and the radiogoniometers have comparatively loose coupling can the circuits be operated satisfactorily in this manner.

Provision must therefore be made that any coupling from S_1 to S_2 is neutralised, and one method of doing this is shown in Fig. 165. Each radiogoniometer is now a double instrument, having two search coils S_1 and s_1 connected in series, and which are fitted on the same spindle and rotate together as in Fig. 166. Each search coil has two sets of field coils, those belonging to one radiogoniometer being connected in parallel across the main aerial loops, whilst those of the other are connected in series with " dummy aerials " which consist of coils wound on small formers and having an inductance which is a function of the field coil and active loop aerial inductances. Again, only one active aerial and one dummy aerial are illustrated for the sake of simplifying the diagram.

If, now, the arrow 1 in the search coil S_1 represents the instantaneous direction of the current due to a signal, it only remains to find out whether the effect of this in the search coil S_2 can be neutralised. Suppose the current represented by the arrow 1 causes an e.m.f. in the field coil F_1 shown (conventionally) by the arrow 2, then the resulting current will flow as shown by the arrows 2, 3 and 4 and will induce an e.m.f. in S_2 as indicated by the arrow 5. Returning to the first circuit again, the S_1 current flowing through s_1, as shown by arrow 6 will induce an e.m.f. 7 and a current 7, 8 and 9 in the dummy field coil circuit and the e.m.f. 10 induced in s_2 will be in the opposite direction round the search coil circuit to the e.m.f. 5 induced in S_2. The dummy aerial circuit therefore anti-couples the search coil circuits, and it will be found that any number of radiogoniometers may be added and that all the search coils are anti-coupled one from another. In such a series-parallel arrangement it is preferable to maintain the parallel connection in the active aerial, in order that the mid-points of the field coils may be earth-connected for purposes already mentioned.

The relation between the inductance of the dummy aerial coils and the rest of the aerial circuit can be easily found. Since all the radiogoniometers are identical it will be clear from Fig. 165 that the condition for balance in, say, circuit 2 due to a signal in the search coil of No. 1, is that the currents produced in F_2 and f_2 shall be equal. Writing down the expression for these currents and equating them, it will be found that if L_A be the inductance of one loop of the active aerial, L_F that of a field coil and L_D that of the dummy, then :

$$L_D = \frac{L_F^2}{L_A}$$

Fig. 167 shows the complete aerial circuits for a set of directional receivers in which the dummy aerial circuit is rendered as symmetrical as possible by winding the field coils in two halves as in the case of the active field coils and connecting them as shown. It will be noticed that the dummy aerial coils are each wound in two halves, each pair being disposed at right angles to one another to prevent mutual inductance between them.

It is not absolutely necessary to split the dummy field coils or dummy aerial coils in this way, and as a directional receiver the system will work quite well with the dummy field coils connected in series with a single dummy aerial coil as in the schematic diagram of Fig. 165. It may also be found an advantage to connect the mid-point of the active field coils of one radiogoniometer only to earth, and not all of them as shown in Fig. 167.

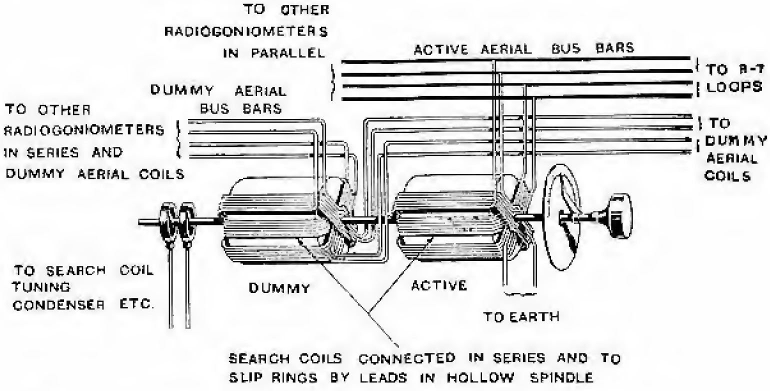


Fig. 166.—Connections of Double Radiogoniometer. (Compare Fig. 284.)

There is a modification of this method of anti-coupling receivers which does not involve the expense of a double radiogoniometer but, since it may affect the accuracy of the directive properties, it is applicable only to directional receiving stations and not to multi-channel D.F. stations. The field coils of any radiogoniometer are each normally wound

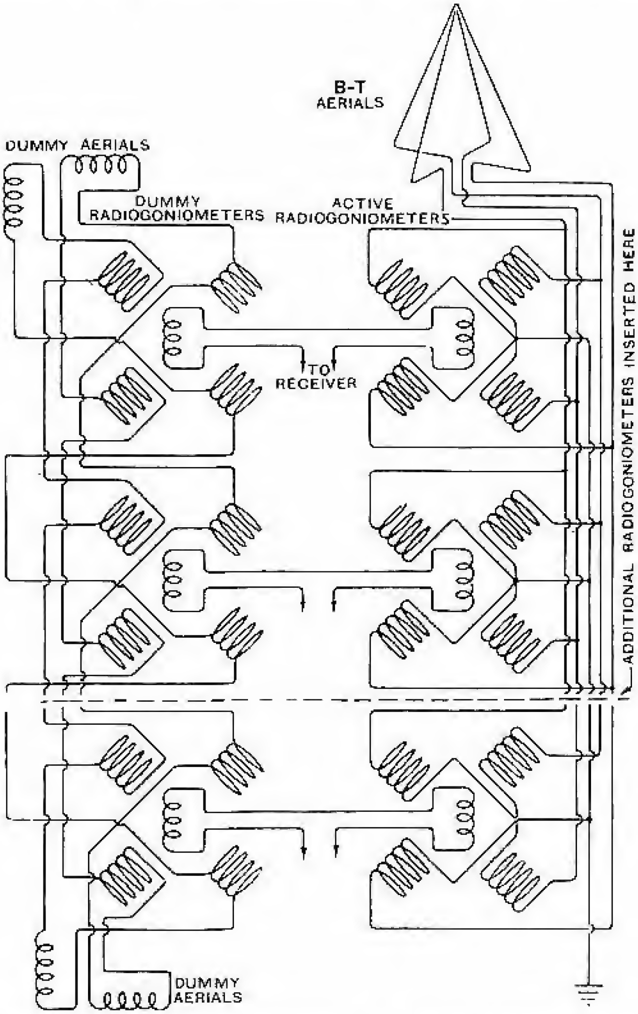


Fig. 167.—Complete Aerial Circuit for Series of Anti-Coupled Radiogoniometers.

in two halves and appear, in plan view, as in Fig. 140, and it is found to be possible to use half of each coil as an active field coil and the other half as the dummy coil, connecting the instrument as shown in Fig. 168. The single search coil now takes the place of the two series search coils of the double radiogoniometer.

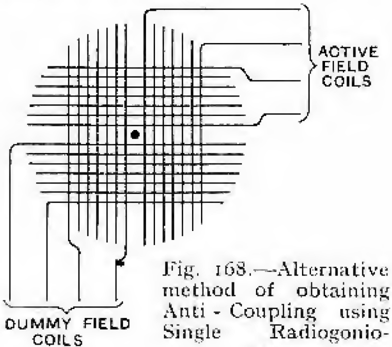


Fig. 168.—Alternative method of obtaining Anti - Coupling using Single Radiogoniometer.

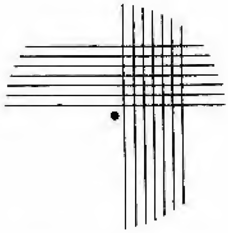


Fig. 169.—Asymmetrical Arrangement of Field Coils in Fig. 168.

Two apparent sources of trouble immediately present themselves. Firstly, since the active and dummy coils are so close together, and parallel to one another, there will be considerable mutual inductance between the circuits; and secondly, both pairs of field coils are now arranged as in Fig. 169, instead of crossing symmetrically in the conventional manner, and this again introduces coupling between the N-S and E-W aerials on both the active and dummy sides.

The first of these points, namely that all the active field coils are coupled to all the dummy coils, does not affect the operation of the system unless the coupling between active and dummy half field coils is extremely tight, as would be the case if they were wound one on top of the other. In such a case, only a very small leakage field would be available to link with the search coil and hence the coupling of the radiogoniometer would be almost zero. With the half field coils placed as in Fig. 168, the mutual inductance is not enough to reduce, appreciably, the linkage of the search coil.

Similarly, the mutual inductance between the N-S and the E-W active or dummy field coils respectively, owing to their being arranged as in Fig. 169, is found also to be insufficient to prevent a perfectly sharp heart-shape minimum being secured.

Fig. 167 may now be redrawn as in Fig. 170, in which the single radiogoniometer with the split coils is used, and the dummy field coils are connected in a simple series circuit with single dummy aerial coils, only one of the active field coil mid-points being connected to earth.

OPEN AERIAL SYSTEM FOR MULTI-CHANNEL STATION

It has been assumed, up to the present, that a separate open aerial will have to be used for each receiver in a multi-channel station, but a method exists for overcoming this disadvantage to some extent and which may even, in favourable circumstances, enable one open aerial to be used for any number of heart-shaped diagrams.

In the method of "valve coupling" an aperiodic open aerial to a receiver, described on page 101, it was arranged that there should be no grid current in the coupling valve. The receiving circuit is therefore "potential operated" and cannot exert any damping effect on the aerial or affect it in any way. This being the case, there is no reason why any number of coupling valves and receivers should not be connected across the same open aerial as shown in Fig. 171, the various search coil circuits selecting from their anode circuits of their respective coupling valves, those frequencies with which they are in resonance.

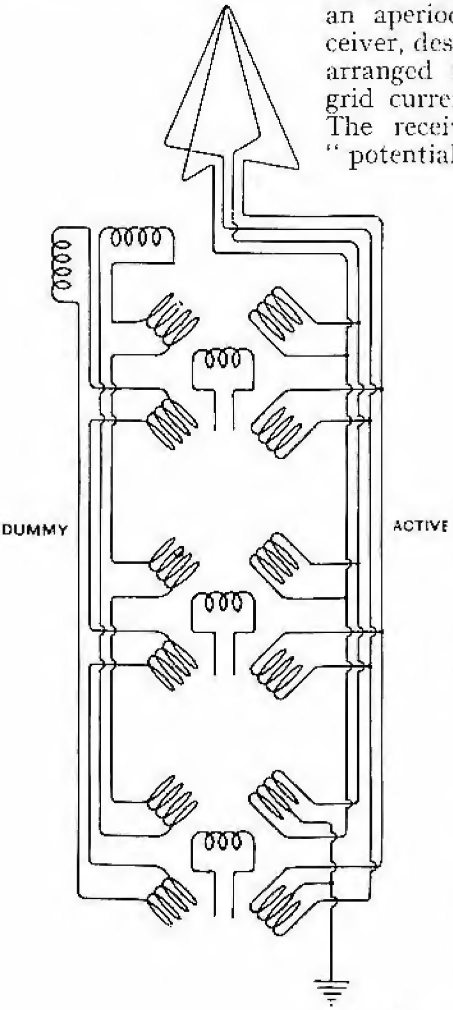


Fig. 170.—Complete Aerial Circuit for Anti-Coupled Radiogoniometers with Split Field Coils.

The receivers, in this case, will be susceptible to jamming due to rectification in the coupling valves, just as already described on page 102, and in a B-T multi-channel receiving station it is often preferable to erect a few more open aerials rather than risk the interference, or the circuit arrangement of Fig. 92 may be adopted. Further reference is made to this question in Chapter 9.

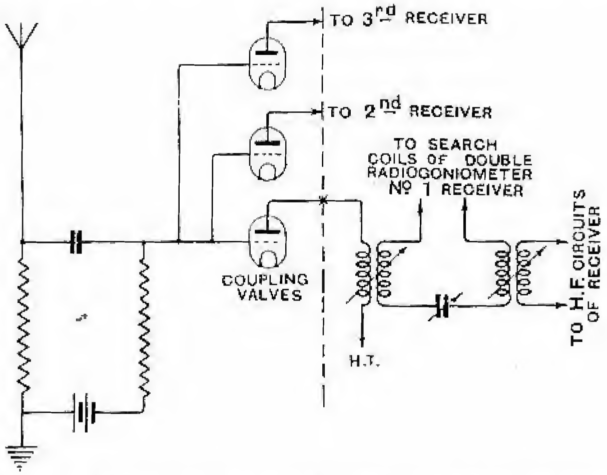

TO 3rd RECEIVER
TO 2nd RECEIVER
TO SEARCH COILS OF DOUBLE RADIOGONIOMETER Nº 1 RECEIVER
TO H.F. CIRCUITS OF RECEIVER
COUPLING VALVES
H.T.

Fig. 171.—Aperiodic Open Aerial, Valve-Coupled to Receivers of Multi-Channel D.F. Station.

CHAPTER 6

POLARIZATION ERRORS, NIGHT EFFECT AND OTHER FREAK PHENOMENA

In Chapters 3, 4 and 5, and also in the installation chapters which follow, a number of possible causes of error in observed bearings are mentioned, together with the corresponding methods which should be adopted to reduce them to within reasonable limits. The most obvious of these are local screening and masses of conducting material near the aerial producing distortion of bearings, which is detected when checking the installation by means of bearings on distant stations, or on a portable transmitting station. Errors of this nature may often be reduced by the methods described under " Choice of Site " and " Calibration."

Antenna effect, Pick-up and Quadrature effects all produce either indefinite or incorrect minima or both together, but are nevertheless easy to detect and eliminate.

In addition to these errors which are associated with the receiving system or the site of the station, there are a number of other factors that give rise to incorrect bearings, some of which are at present beyond our control. The chief of these are :

(1) **Coast Refraction,** or deviation of the direction of travel of the electromagnetic wave on crossing obliquely a sudden change in the nature of the earth's surface. This is also known as **" Land Effect."**

(2) The type of polarization error to which has been given the name of **" Night Effect."**

(3) **Lateral Deviation** of the wave from the plane of the great circle between transmitter and receiver.

COAST REFRACTION

It might not be anticipated that any refraction effects would occur in the case of waves travelling along the ground, but there is abundant proof that a bending of the path of the wave is liable to occur as it crosses a coast line obliquely. Consistent deviations of from 4° to 5° were noticed by T. L. Eckersley in Palestine in 1918 (2009) in the case of waves of 800 to 1,000 m.

which crossed the sea shore at an acute angle. Just as in the case of light waves, the amount of refraction was also found to vary greatly with the wave length when the latter was small, although above 2,000 metres he states that the refraction seemed to be almost independent of the wave length.

This effect has been observed on very many subsequent occasions and—on the assumption that it is due to refraction—it may be noted that the bending of the wave is always in a direction that could be explained by a higher velocity over sea than over land.

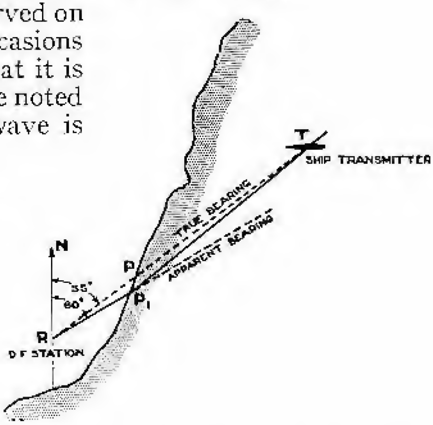


Fig. 172.—Effect of Coast Refraction.

Fig. 172 illustrates a case of coast refraction and its effect at a shore direction finding station R, on the observed bearing of a ship at T. The direct path from T to R is the line TPR but, owing to refraction, the wave front is deflected at the coast, with the result that the actual ray which reaches the frame aerial has travelled by the path TP_1R, making the apparent bearing 5° too great.

The same type of error will be found to exist (page 599) in the case of bearings taken by ships, of shore transmitting stations; the effect being that in certain sectors there is a distortion of the wave front which results in incorrect bearings being obtained, just as intervening coast line may affect bearings taken at a shore station.

Some values for coast refraction errors in connection with the Orford D.F. Station are given in (2722). When the transmission was within 20° of the line of the coast, errors of 3° to 4° were observed on wave lengths of 450 to 600 metres. A systematic increase of wave length from 500 to 2,600 m. resulted in a reduction of the errors from 3·2° to 1·4°. On higher wave lengths, the error was less than 1°.

Similar effects were also noted with respect to the Orfordness Rotating Beacon (page 471), but only on a wave length of 1,000 m. (3129).

Effect of State of Tide. A curious type of variable error has been observed by the British Post Office at their D.F. station at Cullercoats on the North-East coast. The true bearing of North Foreland W.T. station (GNF) from Cullercoats is 154° and the path of the wave runs within a degree or two of being parallel to, and also just grazes, the coast line near the D.F. station. The mean results of a large number of observations show that at high tide the apparent bearing of GNF is 152·75°; whilst at low tide it is 151·5°.

Bearings on stations, the direction of which, from Cullercoats, are such that the path of the wave makes an angle with the coast line of more than 3°, are found to be unaffected by the state of the tide.

It is interesting to note that Bäumler and Zenneck in experiments carried out at German coastal D.F. stations with the express purpose of examining errors, found no tidal effect whatever although refraction was very marked (2608).

Allowances can sometimes be made for these coast refraction errors but this is difficult since the errors vary with the distance between the coast and the transmitting and D.F. stations. Whenever possible, therefore, sites at which such conditions are found to exist should be avoided or, as is commonly done, the directions in which bearings are liable to be incorrect are excluded from the calibrated sector of the station (page 598).

NIGHT EFFECT

The phenomenon to which the above name has been given has for many years constituted one of the most important subjects for research in connection with wireless direction finding. At the time when night effect was first noticed, short waves were not in commercial use and, as the name implies, the effects—on the wave lengths of 300 to 1,000 m. which were used for all navigational purposes until about 1929 or 1930—are most prevalent during the dark or twilight hours. The resulting errors, however, when bearings are being taken on a closed loop D.F., are frequently of such magnitude as to render all D.F. work impracticable.

These errors are now known to be due to the rotation of the plane of polarization of waves reflected from the E and F layers, and occur with even greater virulence on short waves by both day and night. The added complications caused by the skipped distance, with its scattered signals from random directions, and also the combination of direct ray with strong high-angle reflection on certain waves in the short band, necessitate care in the use of these waves for navigational purposes at any time.

The Ultra Short waves, below about 10 m., are coming into increased use for short range aerial navigation. This is partly owing to the absence, under normal conditions, of any reflected ray; also due to the ease with which a desired pattern of radiation can be produced with small aerial dimensions.

Direction Finding by means of waves below about 150 m. differs from that on the long and medium waves in more than a mere matter of degree, and can be studied more profitably after the general subject of polarization errors, the Adcock aerial system and the more practical questions of receiving apparatus and selection of suitable sites.

Chapter 10 is therefore devoted to Short-Wave D.F. work, whilst the Ultra Short Waves in their application to aircraft beacons are mentioned in Chapter 15. The present chapter should be taken as referring to the principles of polarization errors and—except where otherwise stated—to long and medium wave lengths.

Symptoms of Night Effect. It has been noticed, since the early days of directive reception, that the figure eight minima sometimes became indefinite at night, making the operation of taking bearings very difficult. A further effect that was noticed was that the bearings of known transmitting stations were often unmistakably wrong, and that the errors might be anything up to 90° in extent. This has remained a problem up to the present time for all D.F. stations using the closed loop, and when night effects prevail most commercial stations which are not equipped with the Adcock type of aerial make a point of either ceasing work or at least of issuing a warning that the bearings they take should be treated with a certain amount of suspicion.

It is fortunate that the presence of night effect can almost always be detected by experienced operators, and some of the ways in which it manifests itself when using cosine reception are as follows:

(*a*) Minima are indefinite but the bearing is correct on taking a swing bearing and matching intensities on either side of the impure minimum.

(*b*) Minima are crisp but displaced.

(*c*) Minima are indefinite and displaced.

(*d*) In the case of reception of a roughly modulated signal, a change occurs in the character of the note on passing through the minimum point.

(*e*) When position finding by means of cross bearings during night effect periods, a total inability to get intersections is not uncommon, and the " cocked hat " (page 564) may be ridiculously large.

(*f*) Rapid variations take place in the intensity of signal strength, which falls at times to zero.

(*g*) When using a balancing circuit for reducing quadrature effect, the auxiliary aerial coupling has to be considerably tighter than normal.

Types (*a*), (*c*) and (*d*) are not dangerous in that they are recognisable, but type (*b*) can only be detected (when using ordinary figure eight reception) by watching the bearing for some time to see whether it is constant or variable, or by taking check bearings on stations, the true bearings of which are known. This latter type of checking will not always show up the effect, since, as we shall see later, the extent of the error is dependent upon the transmitted wave length and also on the distance between the transmitting and receiving stations, so that one station may exhibit the effect whilst another does not.

Period of Night Effect Conditions. The extent of the errors due to night variations alters considerably with the time of the year, the part of the world and a number of other factors, but in general it may be said that " night " receiving conditions are liable to start one hour before sunset and continue until one hour after sunrise. Under certain winter conditions in latitudes higher than about 65° North, true " day " conditions may scarcely exist at all except during a short mid-day period, so that the calibration of important D.F. stations must be confined to these hours if possible.

Early Investigations of Medium and Long Waves. As would be supposed, the existence of these extreme variations in apparent bearing has attracted the attention of wireless research engineers and physicists in this and several other countries, notably the United States and Germany. The references to a large number of published accounts of the work are to be found in the Bibliography, but there is not space to deal here with more than a few of the tests that were made.

A point in connection with these notes that may surprise the present-day student is the order of the wave lengths mentioned, but it must be remembered that for trans-Atlantic working and over any very long distances prior to about 1925, wave lengths of 6,000 to 20,000 m. were the only means of radio communication. Indeed, high-power stations on even longer wave lengths than these were being planned when the reintroduction of short waves occurred.

In England the earliest records were published immediately following the European War by Round (2001) and Wright (2025). Unfortunately, although based on four years of D.F. work and wide experience, neither of these published accounts gives actual tabulated data on the subject of variations in bearings, though both agree that night variations are more pronounced on continuous waves than on damped ones. Wright adds that the presence of night effect can usually be distinguished on spark signals since in this case a sharp displaced minimum is exceedingly rare. In the United States, A. H. Taylor (1924) observed errors on continuous waves, of 4,000 to 16,700 m., varying from a few degrees up to nearly 90° and stated that, in general, variations were greater on longer than shorter wave lengths when the distances were great. At a distance from the transmitter of 250 miles, mostly over land, he observed errors of 30° on spark transmission with a wavelength of 1,500 m.

Kinsley and Sobey (2014) in America stated as a result of tests that continuous waves of 4,900 to 17,300 m. showed greater errors when under the influence of night variations than did spark transmission on 960 m. to 5,700 m. Errors up to 50° were observed, at distances varying from 40 miles to 7,500 miles, and a number of cases occurred during the tests when no definite minimum could be found during bad periods of night variations. This effect was noticed on both spark and C.W. transmissions. Kinsley and Sobey give details of a number of different types of night effect which they observed, and make suggestions as to the possible mechanism of the distortion of the wave, including the possibility of the Heaviside Layer being the cause.

In 1921 T. L. Eckersley (2105) introduced his theory of the cause of night effect and this is discussed on page 203. He also stated that whilst in northerly latitudes, such as England, the variations were the most acute during the period around the time of sunset; in places further south, such as Cairo and Salonika, the variations continued through the night and were on the whole more violent. Eckersley also considered that above 300 m. the variations appeared to be about the same on all wave lengths as far as 5,000 m., but were never observed at ranges of less than about 20 miles. Errors up to 25° were observed. It is not stated whether the transmissions were all on C.W. or not.

In 1921 G. M. Wright and S. B. Smith (2112) gave the results of night effect observations in which errors of +90° and

—90° were noted on wave lengths of 5,000 and 6,000 m. continuous wave transmission. These tests are discussed in greater detail on page 205.

In 1922 Pickard in America carried out observations at Otter Cliffs, Maine, on the variations in apparent direction of European stations (2207) and found that the average night variation on Bordeaux and Nauen was 12°. He also noticed that the errors on San Diego were greater than on the European stations.

Mesny, in 1922, in France, observed errors in bearing up to 90° on C.W. stations, of 10,000 to 25,000 m., at ranges of 200 to 600 miles over land. Spark stations at a distance of 30 miles over land exhibited errors up to 10° or 15° on wave lengths of 600 to 1,000 m. On the spark stations it was at times impossible to take bearings at all owing to the flatness of the minima. Mesny expresses the opinion that the observed differences between the behaviour of spark and C.W. transmission are due to a wave length effect and not to the damping of the wave (2216).

Radio Research Board Investigations. During 1922 and 1923 the Radio Research Board (2420) made a series of investigations on wave lengths of 450 and 600 m. on both ship and shore stations, the tests being carried out by R. L. Smith-Rose, who summarises the results as follows: "The general conclusion drawn from the experiments is that when the path of the transmission is entirely over sea and in a direction making an appreciable angle with the coast line so as to be free from coastal refraction effects, the accuracy of radio direction finding is sufficient for many navigation purposes up to ranges approaching 100 miles. Observations taken on various land stations with spark transmitters on wave lengths of 450 and 600 m. show that for greater distances over sea, the variable 'night' errors encountered are of a much higher order. When the propagation of waves is entirely over laud the corresponding variations are encountered at shorter distances."

A further paper by Smith-Rose on the effect of wave damping upon D.F. (2509) described tests which involved some 10,000 bearings on a large variety of wave lengths and on spark and C.W. stations, made with a view to arriving at some definite conclusion as to the comparative reliability of the two systems of transmission during night effect. The opinion of the author was that the errors were equally likely to occur on either system, and that so far as the use of the D.F. for marine navigation was concerned, continuous waves whether modulated or not could be used in all cases where spark waves had given good results, though it might be advisable to make further trials with regard to the pure C.W. transmission as the evidence on this point was not conclusive.

In a later paper by Smith-Rose and Barfield (2617) the authors give an account of apparent rotations of C.W. bearings of more than 360° on 386 m. and their error curves are shown in Fig. 188.

The authors, however, regard this as exceptional in view of the fact that out of 164,000 observations made on another occasion on spark and continuous waves between 2,000 and 12,000 m., only three cases were experienced of an error exceeding 90°. These tests are described in a Radio Research Board Report (2521).

Some more recent observations are quoted later in the chapter and remarks on the present-day use of I.C.W. in place of spark transmitters appear on pages 192 and 227.

Night Errors on Equi-Signal Aircraft Beacons. In 1927, night errors were observed on the equi-signal courses of the U.S. Bureau of Standards aircraft beacon transmitters, and are described by Pratt (2813) and Diamond (3301). The principle of operation of these beacons is given on page 474. In mountainous country the course variations to right and left began at 20 to 50 miles, and were at times bad enough to render the beacons useless at 30 miles; the errors being more than 10° and making it impossible for the pilot to keep a course even by averaging the course indications. The wave length used was 1,030 m. (see Fig. 379). Tabulated and analysed results are given in the above references which show that, on the whole, the variations were more violent over mountainous than flat country, were greatest on winter nights, appreciable on winter days and least on summer days. In one series of tests, at 65 miles from a beacon, over mountains, some 4,000 observations were made during 13 nights, average course variations for each night varying from 8° to 29° and the percentage number of observations per night with errors of over 45° varying from 0 to 44%. Errors of 90° were not uncommon.

Night Effect "In the Air." It is interesting to note that up to approximately the time of the tests just mentioned, it was frequently maintained that night effect was never experienced in aircraft and the expression "No night effect in the air" is met with in several papers on D.F. between 1920 and 1928 (2808).

Errors are actually quoted by Kiebitz in 1917 (2022) when describing experiments with early aircraft equi-signal beacons in Germany, but there is some doubt as to how much of this was due to genuine night effect and how much to " aeroplane effect," which is mentioned below.

Night Effect and Marine Navigation. For the purposes of navigation of ships at sea it is clearly of the greatest importance to know to what extent reliance can be placed upon D.F. bearings, and the situation may be summed up as follows. With Modulated or I.C.W. transmission on wave lengths above 450 m. up to distances of 80 miles over sea, the errors due to night effect will be very small and not usually more than two or three degrees. At greater distances, or over land, or on continuous wave transmission, bearings, when night effect conditions are prevalent, are unreliable when a normal closed coil or B-T Direction Finder is being used.

AEROPLANE EFFECT

A short investigation of what has been referred to as " aeroplane effect " may form a useful introduction to the main section of this chapter dealing with the causes of night variations in bearings.

In Chapter 2 mention has been made of the way in which an abnormally polarized wave is radiated from the trailing aerial of an aeroplane, producing, in a direction abeam, a wave front of the form shown in Fig. 10. It will be shown directly that it is possible for a wave front of this kind, when arriving at a D.F. station with an angle of incidence which is less than 90° (that is to say, not horizontal), to produce errors which vary from 0° to 90° depending on the degree of polarization.

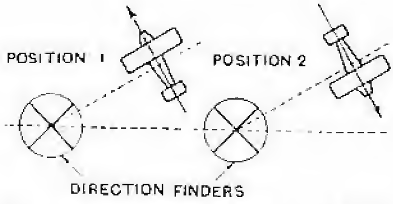


Fig. 173.—Aeroplane Effect (Jour.I.E.E.)

In his paper " Direction and Position Finding " (2001), Round gave an interesting account of the first observations of this effect during the European War by Adcock in France and independently also by Eckersley in Egypt ; and Eckersley, in his theory of the cause of Night Effect, attributes the errors to waves of much the same form as these aeroplane waves, but which are radiated from normal shore aerials and which become abnormally polarized by external agencies.

Adcock has subsequently (2617) given some details of his observations on aeroplanes in 1918. Fig. 173 shows two positions of an aeroplane in flight, the bearing of which is being taken by a ground D.F. station. In both positions the aeroplane is flying at right angles to the line joining it and the D.F., but the direction of flight is reversed in the second case. The effect of this will be that the trailing aerial, as viewed from the ground D.F. station, will, in position two, appear similar to that of the aeroplane in Fig. 9 and will produce a wave front as in Fig. 10. In position one, it will be sloping from left to right and will produce a wave front at the D.F. in which the lines of magnetic flux are correspondingly changed in direction. A series of bearings were taken on the aeroplane when it was directly over four villages, the distances of which were known, and the results are tabulated below.

Aeroplane flying over	Approximate distance of aeroplane from direction-finder.	Approximate true bearing of aeroplane from direction-finder.	Error of bearing on aeroplane as recorded by direction-finder with revolving-loop aerial.	
	miles		Aeroplane in position No. 1 (Fig. 173).	Aeroplane in position No. 2 (Fig. 173).
Village A	3	65°	—	– 21°
Village B	4	67°	+ 24°	– 33°
Village C	5½	66°	+ 31°	– 23°
Village D	8	63°	+ 40°	—

From these figures it will be seen that errors up to 40° are produced and also that the sign of the error is reversed when the aeroplane is flying in the opposite direction.

Investigations regarding the waves radiated by aircraft have also been made by Baldus and Buchwald (2021), Burstyn (2023), and Buchwald and Hase (2019).

A case of the reverse effect, namely, of an aircraft D.F. observing an error in the apparent position of a ground station, is referred to on page 202, whilst aeroplane effect on the U.S. Radio Range Beacons is mentioned on page 516.

Observing the behaviour of the closed coil D.F. when used under the influence of these abnormal waves, it will be found that the positive and negative errors can be accounted for in quite a simple manner.

Relation between the Direction of Rotation of the Plane of Polarization and the Direction of Rotation of the Apparent Bearing. In Chapter 2 it was seen that in the case of downcoming waves with horizontal polarization, the directional effect due to magnetic linkage became vested in the horizontal limbs of the loop and produced an error of 90°, but it is interesting to notice how the position of the frame aerial changes, say for minimum linkage, as the degree of polarization is gradually varied. Since this involves movements in three dimensions, plane diagrams cannot easily be adapted to illustrate the conditions at all clearly. The reader will find it far more instructive to take a book in one hand to represent the frame aerial and a pencil in the other to act as a line of magnetic force, and satisfy himself as to conditions for maximum or minimum linkage with various degrees of polarization.

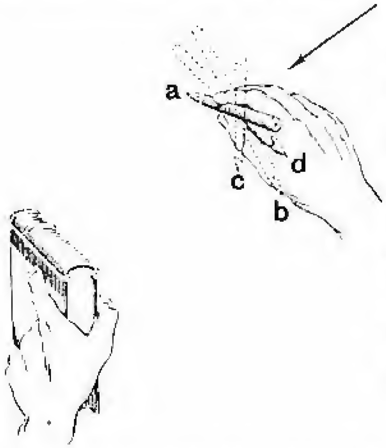


Fig. 174.—Position of Frame for Zero Magnetic Linkage with Vertically Polarized Downcoming Wave

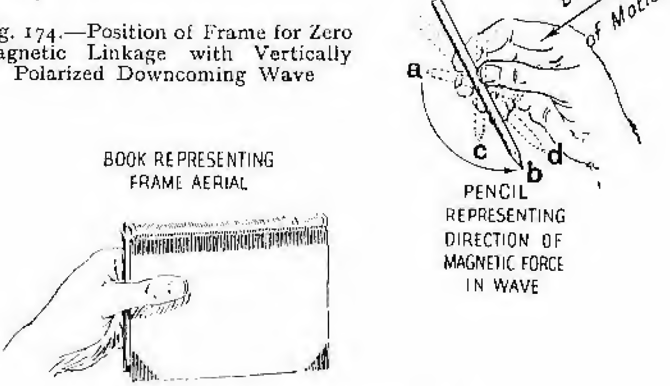
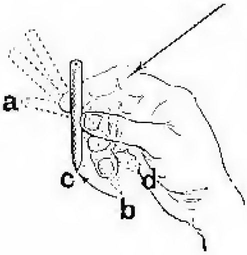

Direction of Motion
a
c
d
b
BOOK REPRESENTING FRAME AERIAL
PENCIL REPRESENTING DIRECTION OF MAGNETIC FORCE IN WAVE

Fig. 175.—Compare Fig. 49.

Suppose the pencil in position *a*, Fig. 174, to represent the direction of magnetic force in a downcoming wave arriving in the direction of the arrow, the wave being polarized vertically, and therefore having its magnetic flux horizontal and at right angles to the plane of propagation of the wave. In such a case the position of the frame aerial, represented by the book, for zero linkage with the magnetic flux, will be as shown.

Next consider the plane of polarization to be rotated through a right angle so that the direction *b*, Fig. 175, now represents the magnetic force. Then, for zero linkage, the book will also have to be twisted through a right angle.

It is more important, however, to study the positions of the book for intermediate positions of the pencil. In Fig. 176 the pencil in position *c* is shown rotated through 45°, back towards the original position, and is hence midway between the positions *a* and *b*. In this case it will be found that the book also has to be twisted through an angle in order to keep it parallel to the pencil. If, however, the pencil be rotated 45° in the reverse direction, as shown in *d*, Fig. 177, then the book must also be rotated by the same amount in the reverse direction to maintain zero linkage.



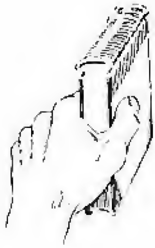
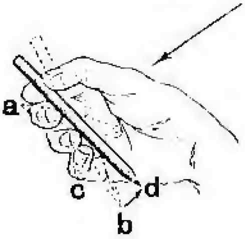


Fig. 176.—Position of Frame for Zero Magnetic Linkage when Magnetic Force is in the Direction *c*



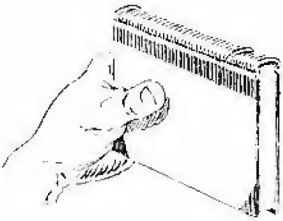


Fig. 177.—Position of Frame for Zero Magnetic Linkage when Magnetic Force is in the Direction *d*.

The manipulation of a book and pencil in the above manner, for a short time, will make clear many points concerning the reception, by means of a simple frame aerial, of waves with varying degrees of polarization, and it will be noticed particularly that the degree and "sense" of the distortion of the apparent direction of an incident wave is governed by the degree and "sense" of the rotation, from normal of the plane of polarization.

Assuming that abnormally polarized wave systems of this nature actually exist, in addition to the ones radiated from aeroplane aerials, and it has, of course, been proved beyond all doubt that such is the case, T. L. Eckersley has shown that most of the symptoms of night effect can be explained. The indefinite minima, variations in signal strength, distortion of bearing and other effects, may all result from the changing phase relationships between the normal direct wave from the transmitting station, and these abnormal waves which reach the receiving frame by other paths, and arrive with a downward direction and a component of vertical magnetic flux.

The Practical Case. In practice, the error produced by any given wave is complicated by several factors. Firstly, the loop is usually near enough to the ground to be influenced very appreciably by the reflection of the downcoming ray, and in the case of medium and long waves there will generally be a direct ray in addition to the indirect one. Again, the indirect ray may have a rotating field and the whole idea thus passes beyond the scope of the book and pencil illustration. The mathematics of the subject taking into account the relative strengths of the fields in the rays, the angles of incidence and of polarization, the coefficient of reflection at the earth's surface, the dimensions of the loop and its height above the earth together, of course, with the frequency of the signal, cannot be given here but should be studied in some of the references given later for a proper understanding of the problem.

The Standard Wave Error. Owing to the number of variables and their range of variation, a great stumbling block in the comparison of different types of receiving aerials, with regard to their susceptibility to error, has been the difficulty in selecting a type of wave on which tests might fairly be made as representing average bad error conditions. Barfield, in his development of the Adcock aerial (3504) encountered this trouble and his adoption of a Standard Wave Error is of interest.

Referring to this, he says: "The greater part of the work has been devoted to the investigation of the directional characteristics of the systems when under the influence of waves of any given angle of incidence or state of polarization. In order to sum up the performance of a given system in this respect into a single figure instead of a whole family of curves for every angle of polarization, it has been found convenient to select, as an arbitrary standard of comparison, the error for one particular angle of incidence and angle of polarization and to use this as a figure of reference or performance. Hence the wave for which both these angles are 45° is referred to as the ' standard wave ' and the error produced thereby in the system is called the ' standard wave error ' of the system. . . . For simplicity it is assumed that the e.m.f.'s induced in the system by the horizontally and vertically polarized components are in phase. The ' standard wave ' would therefore be not linearly but elliptically polarized, and should thus be defined as having equal horizontally and vertically polarized components with a suitable phase relationship to fulfil the above condition."

The reason that the indirect ray has to be elliptically polarized to produce a linearly polarized standard wave is because the latter is the resultant of the original ray and its reflection from the ground, in which process the horizontally and vertically polarized components undergo different degrees of phase shift.

The standard wave error for the closed loop is about 35° for all wave lengths and soil conductivities when the size of the loop and its height above the ground are small in comparison with the wave length. In its application to the various forms of Adcock aerial that follow, the calculation of the error is less straightforward and varies considerably with both these factors. The matter is referred to again in Chapter 7.

THE LOOP TRANSMITTER

The polarization errors that occur when using a loop transmitter and a non-directional receiver are an interesting example of the law of **reversibility** which is applicable to so many mechanisms and natural processes. This law may best be defined by a mechanical example as, for instance, that if the application of air in movement to the sail rotor of a windmill causes the rotor to move and to generate electrical energy in a suitable machine, then, in general, the application of electrical energy to the machine will in turn cause the rotor to move and produce movement of air. Applied to wave propagation, the law states that the conditions governing, at any instant, the propagation of electromagnetic waves from a point A on the earth's surface to another point B are the same as those governing the transmission from B to A.

The application of the law of reversibility to wave propagation is sometimes contested, but it is, at any rate, substantiated by the behaviour of the loop transmitter which, as has been seen on page 191, has led to serious difficulties in operating the U.S. equi-signal aircraft beacons. See also (2909).

In Fig. 178 (*a*) a vertical loop is shown, and the currents in the vertical limbs, with their associated magnetic fluxes are indicated. The flux due to one limb is shown by solid and that due to the other by dotted lines. Along the XX axis, the resultant field due to the two sets of flux will clearly be zero as they are equal in strength and in phase opposition, and it is easy to see that anywhere in the vertical plane through XX there can never be a resultant field due to the current in the vertical limbs.

On the other hand there will be a resultant field in the horizontal directions YY, and a gradually reduced resultant field in the vertical plane through YY for increasing angles of elevation.

Fig. 178 (*b*) shows in the same manner the fields due to the currents in the horizontal limbs. As before, in the horizontal direction XX, the two fields cancel out, but as the angle of elevation increases, the phase opposition decreases and the horizontal limbs are seen to have a cosine diagram of radiation in the vertical plane through XX just as the vertical limbs had in the horizontal plane. This upward radiation is, of course, horizontally polarized and so cannot produce a signal in a vertical receiving aerial, so that nowhere in the vertical plane at right angles to the transmitting loop can a signal normally be received on a vertical aerial.

If, however, these upward rays be reflected down to a distant receiver after having undergone distortion of their plane of polarization, then their vertically polarized component will be capable of producing a signal on a vertical aerial along the normal line of zero reception, and probably a zero signal will result along some other direction, with consequent error.

Thus the error with either a receiving or a transmitting loop is always dne to the reception on, or the radiation from, the horizontal members, combined with distortion of the plane of polarization en route.

For a mathematical analysis of the errors due to a transmitting loop used as a beacon, see Smith-Rose (2810).

DIRECTION FINDING IN THREE DIMENSIONS

From time to time there have been put forward apparently ingenious methods of finding the complete direction, say, of an aircraft transmitting station, by means of a system of frames capable of rotation in more than one plane. By "complete" direction is meant the vertical angle of the incoming signals

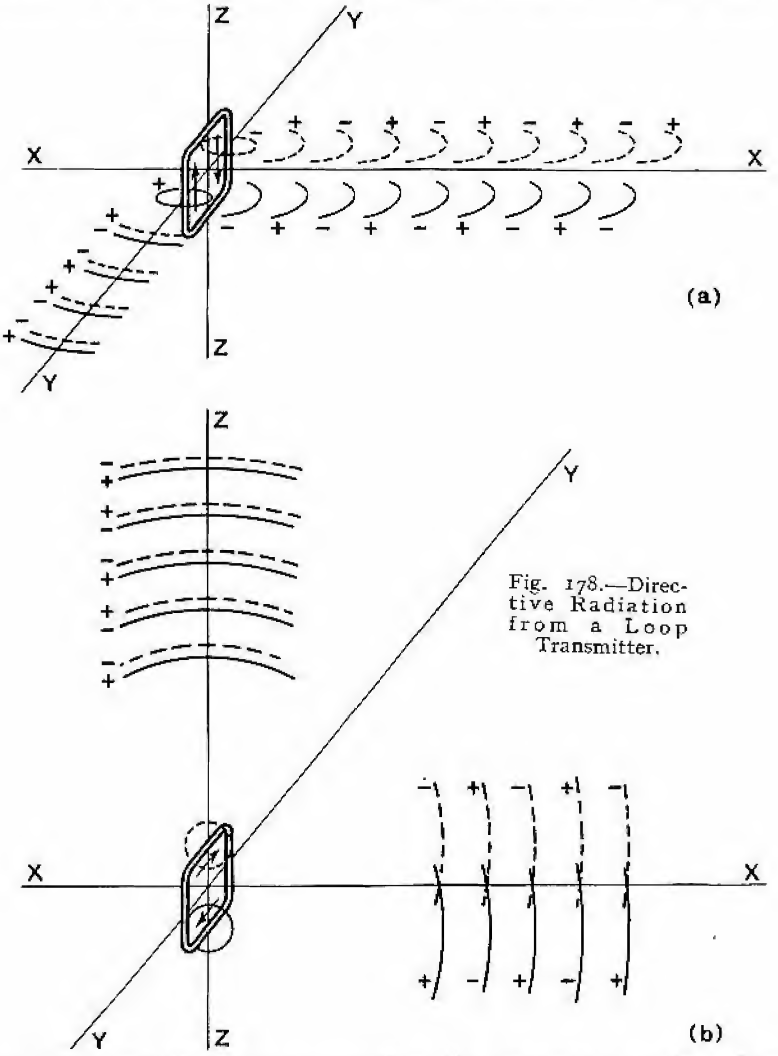


Fig. 178.—Directive Radiation from a Loop Transmitter.

at the receiving station as well as the horizontal angle. The futility of certain such devices can at once be appreciated from what has been said in this chapter concerning reception by frame aerials.

To consider the case that is illustrated diagrammatically in Fig. 179, suppose that A is a frame aerial mounted in a vertical plane and free to rotate about a vertical axis. To this frame is attached a base which supports a second frame B, which is free to rotate about a horizontal axis parallel to the plane of the vertical frame, as shown. Now, suppose it is desired to take bearings on a station from which the signals are arriving with some acute angle of incidence. Suitable receiving circuits being associated with the two frame aerials, the frame A is rotated until the minimum signal strength is obtained, when the centre line of the system XY is assumed to be in the horizontal direction of the transmitting station. The frame B is then rotated in an attempt to obtain the vertical angle of incidence.

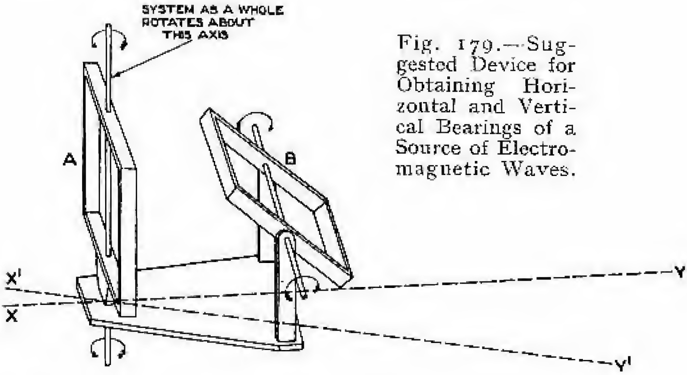


Fig. 179.—Suggested Device for Obtaining Horizontal and Vertical Bearings of a Source of Electromagnetic Waves.

If the wave arriving at the receiver is a vertically polarized one, then, since the magnetic field will be parallel to the earth's surface, no signals can ever be obtained on the B frame, since there will be no linkage for any position of the frame. On the other hand, the A frame will give the correct horizontal bearing.

If, however, the wave radiated is not vertically polarized, which we have seen to be frequently the case with aeroplane transmitters, then the results will be still less satisfactory. The A frame will now have its position of minimum reception when its plane is in some direction X′ Y′, owing to the abnormally polarized component in the received wave, thus distorting the horizontal bearing.

Under these conditions both the vertically and horizontally polarized components of the wave will be received by the B frame. The vertical magnetic field will cut the frame in all positions except when at right angles to the vertical direction of incidence, so that, so far as this component is concerned, the correct vertical angle should be indicated. Owing to the fact, however, that the whole system is rotated from the correct horizontal bearing XY to the incorrect one X′Y′, the horizontal frame will now also be cut by the horizontal magnetic field, thereby distorting the otherwise correct bearing in the vertical plane. The frames have been supposed to be in free space but, if near the ground, the reflected wave will still further complicate any attempt to take a correct bearing.

CAUSES OF HORIZONTAL POLARIZATION IN REFLECTED RAY

Form of Transmitting Aerial. Certain types of transmitting aerial radiate a wave which has a vertical component in its magnetic field ; one such aerial is the common inverted L pattern. The portion of the wave propagated from this aerial over the earth's surface in a horizontal plane is normally polarized, but that portion of the wave which does not leave the aerial in this plane, but travels upwards, may have a vertical component of magnetic force and, on being reflected at the conducting layer, will reach the receiving frame and give rise to distortion of bearings.

Thus, in Fig. 180, A represents the progress of a portion of the wave front of the normal wave between the shore station shown and the distant receiving station. This wave can have no vertical component of magnetic field owing to the proximity of either the surface of the earth or sea (page 22). The portion of this normal radiation which leaves the aerial in a direction making an acute angle with the earth's surface is shown by V_1, and during the dark hours this wave will also reach the receiver by reflection from the E layer, and may arrive normally polarized, or abnormally, according to circumstances. In addition to these two waves, there is also radiation from the horizontal portion of the L aerial, which will have its magnetic field vertical, as represented by H_1, and this wave, on reflection from the conducting layer, will give rise to distortion of bearings. The effects of this latter radiation can never be noticed during the daylight hours, since it can only reach a ground receiving station at a distance by reflection, the vertical magnetic field being dissipated at the earth's surface.

In the early days of direction finding during the European War, 1914–1918, K. Tremellen noticed that when taking bearings on two different transmitting stations which were situated close to one another and working on similar wave lengths, but which had different types of aerial, the apparent bearings during the dark hours were several degrees different, whilst during the day they were the same (2001). P. Franck mentions an instance (2409) of an apparent error in bearing of a ground station, as measured by a frame D.F., from an aeroplane in flight. The error was observed to vanish when the aeroplane was in the same vertical plane as the aerial. It is interesting to compare this with Adcock's observations, mentioned on page 192.

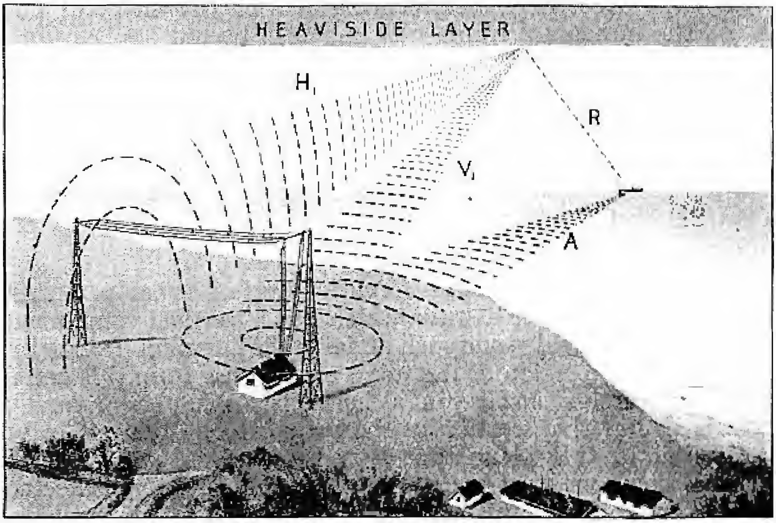


Fig. 180.—Method by which Abnormally Polarized Wave H_1 Radiated from Horizontal Portion of an Aerial, may reach a Receiving Station by Reflection.

A series of experiments carried out by R. L. Smith-Rose for the Radio Research Board (2422) over a period of six months in 1923 did not provide a very definite confirmation of these observations. Various types of transmitting aerial were employed, and the apparent bearing of the transmitter was observed by day and night, the conclusion arrived at by Smith-Rose being that whether the transmitting aerial was a vertical one, an inverted L or the T pattern, the apparent bearings were consistent during the day and all equally erratic during the normal periods when night variations were present.

He therefore formed the opinion that an absolutely symmetrical transmitting aerial from which no vertical magnetic force is radiated, may still produce night variations to the same degree as an unsymmetrical one.

Magneto-Ionic Causes. The rotation, in the ionosphere, of the plane of polarization of a wave, due to the effect of the earth's magnetic field upon the moving electrons, has already been briefly mentioned on page 31 and this, together with other associated processes, is the most prevalent cause of change of polarization of a reflected wave.

T. L. ECKERSLEY'S THEORY OF NIGHT EFFECT

Relative Phases of E.M.F.'s Induced in a Receiving Frame by the Direct and Reflected Waves. The phase of the induced e.m.f. in a receiving aerial, relative to the phase of the e.m.f. in the transmitting aerial, is a function of the wave length and the distance between the receiving and transmitting stations. In Fig. 181 the sine curve drawn from the transmitting station T to the receiving frame aerial R_1 is to be taken as a measure of the instantaneous intensity of the electromagnetic force in the path of the wave. It will be noted that the receiving station is ten complete wave lengths from the transmitter. When discussing the method in which a frame aerial receives in Chapter 3, we saw that when the flux in the wave was a maximum, the e.m.f. round the frame was zero, so that in the case illustrated the e.m.f. in R_1 is zero. Had the receiving aerial been, say, at R_2 which is three-quarters of a wave length further away from T, then, at the same instant, the intensity of the flux in the wave would have been zero and hence the induced e.m.f. a maximum. From this we see that the distance is a factor which governs the relative phases of the e.m.f.'s in T and R.

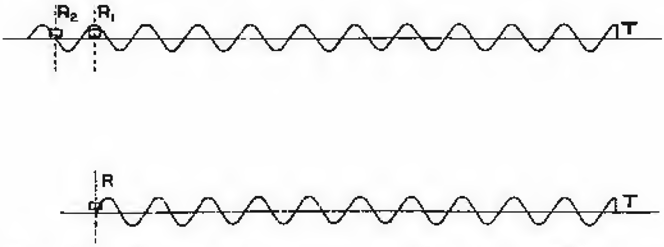


Fig. 181.—Phase Relations of Transmitting Aerial E.M.F. and Receiving Aerial E.M.F., as a Function of Distance between the Stations and of Wave Length.

In the lower figure we have kept T and R the same distance apart, but the wave length has been slightly reduced, and we now see that R is at a point of zero flux intensity, indicating that the phase of the e.m.f. in R, relative to that in T, is also a function of the wave length.

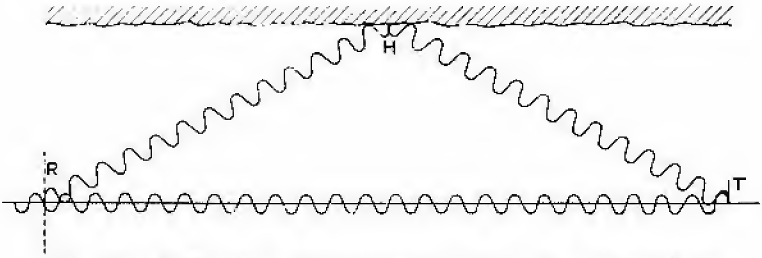


Fig. 182.—Interference Effect between Direct and Reflected Rays.

Referring to Fig. 182 it is easy to see that, since the path of the reflected wave THR is greater than that of the direct path TR along the surface of the earth, the two waves may arrive at R with any degree of phase difference, depending on the relative lengths of the two paths and also on the transmitted wave length. The two waves are here seen to be arriving at R exactly 180° out of phase, so that, if their mean intensities are equal and if both waves are vertically polarized, the e.m.f.'s which they induce in the receiving loop will be in opposition and no signals will be received so long as the condition lasts. A change in wave length, or a change in the length of the path of the reflected wave, will cause a readjustment of the phase relations at R, and signals will then be heard, the intensity varying from zero, in the case of phase opposition, to a maximum when the two waves are exactly in phase with one another.

Since the direct ray, in the above instances, is travelling over the earth's surface, it must arrive at the receiver normally polarized if it arrives at all, whilst the indirect ray is subject to no such restrictions along its path and may arrive polarized in any plane, or elliptically, and hence capable of producing errors in the closed loop D.F. (page 67).

It is important to notice that if the reflected wave is normally polarized, no distortion of the observed bearing at R will take place, no matter what the angle of incidence may be.

Summarising the causes of Night Effect according to Eckersley's theory, we see that the following three component waves are all influencing the frame aerial during night effect periods :

A. The direct, vertically polarized wave.

B. The vertically polarized component of the reflected wave which produces the normal figure eight diagram, but which is not necessarily in phase with A. (Owing to the varying phase relationship between A and B, and also owing to their varying relative amplitudes, the resultant polar curve of reception of the frame may vary greatly in amplitude, although the direction of the minimum remains correct.)

C. The horizontally polarized component of the reflected wave which produces a figure eight diagram, having its minimum in the plane of the frame (90° in error). This component may or may not be in phase with B, and depending upon the instantaneous phase and amplitude relations of the A and B rays, this component may cause very considerable distortion of the direction of the minimum of the simple frame.

In subsequent parts of the chapter, when discussing the " mechanism " of the distortion of the minimum by means of vector and polar diagrams, representing conditions met with in practice, the above three component waves will be referred to by the letters A, B and C.

EXPERIMENTAL CONFIRMATIONS OF ECKERSLEY'S THEORY OF NIGHT EFFECT

Wright and Smith's 90° Error Observations. It has been known for many years, and has become popular knowledge since broadcasting began, that variations occur in the night intensity of long- and medium-wave signals in addition to the errors in apparent bearings.

In 1920 G. M. Wright and S. B. Smith (Marconi Co.) made a series of synchronized observations of signal strength and bearing variations, using both cosine and cardioid reception (2112). Though similar results have been reproduced many times subsequently by other workers, and possibly in more spectacular form, these early experiments are quoted in some detail partly as being the first published data of the kind and partly because, owing to the long waves used, the effects take place slowly enough for a close examination to be made.

Fig. 183 illustrates a type of extreme variation in bearing which is sometimes exhibited about the time of sunset at either the transmitting or receiving station. In this case the signals were being received at Chelmsford, Essex, from the

French high-power station at Lyons, reception being carried out on a B-T circuit. It will be noticed that from about 8.20 p.m. the observed bearing began steadily to decrease,

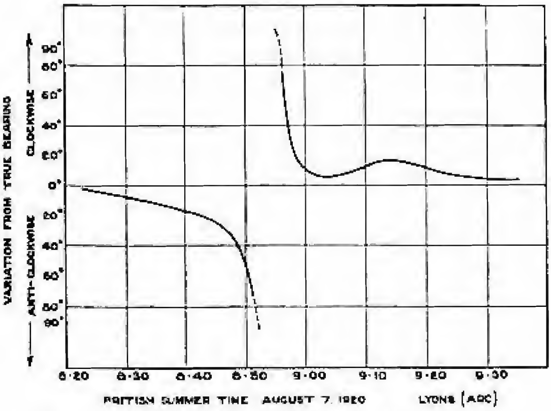


Fig. 183.—Example of Extreme Variation in Apparent Bearing.

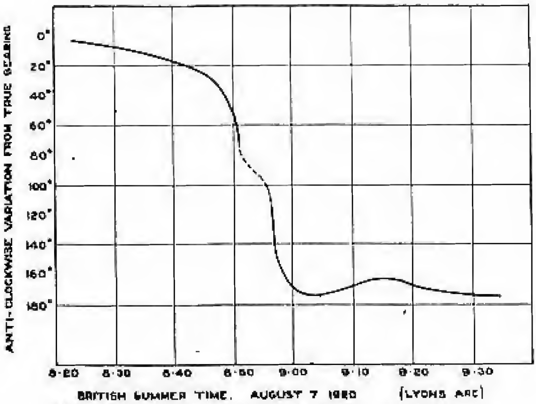


Fig. 184.—Alternative Method of Plotting Graph of Fig. 183.

and at 8.50 p.m. was decreasing at a rate of about 8° or 10° per minute. At 8.52 p.m. the bearing was nearly 90° in error, and as the minimum had been getting more and more indefinite it became practically impossible to observe the bearing for a period of three or four minutes.

The minimum then began to become more definite again, and was found to be almost 90° in error in the opposite direction and rapidly returning to normal; so that by 9.5 p.m. the bearing was almost correct again and had settled down to the usual slight night variation.

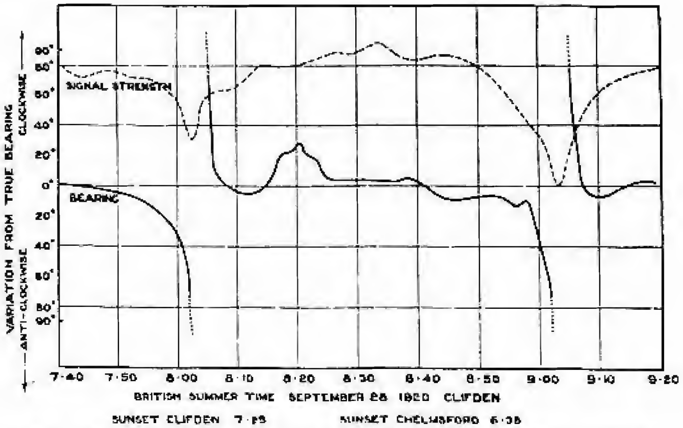


Fig. 185.—Another Example of Extreme Sunset Variations in Apparent Bearing.

Owing to the 180° ambiguity of the simple frame diagram of reception, the performance might equally well be represented by Fig. 184, in which the error is shown steadily to increase to 180°, instead of swinging abruptly from $-90°$ to $+90°$ and returning to zero, and until we have formed some idea of the mechanism of the effect it is difficult to say definitely which of these explanations represents the true state of affairs.

In Fig. 185 are illustrated two similar occurrences in the case of reception at Chelmsford from a 6,000 m. C.W. transmitting station at Clifden, Ireland. Measurements of signal strength were also taken and a marked reduction in signal strength is noticeable at the centre of each cycle of variation of bearing. In the second instance, at 9.4 p.m., the signal intensity actually fell practically to zero for a short period.

Mechanism of the 90° Error Phenomenon. A simple and very interesting explanation of the above effect is afforded by Eckersley's theory. We will assume that a vertically polarized direct wave (A), and also a reflected wave which has a vertically polarized component (B), and a horizontally polarized component (C), are being received on an ordinary frame. Now it is conceivable that owing to absorption effects, etc., the A wave may be reduced in amplitude until, at the

D.F. station its intensity is equal to that of the B component of the reflected wave.

Smith-Rose has observed (2422) that it frequently happened in certain D.F. tests he was carrying out that the signal strength from a station during the day, when the search coil was in the position of maximum, was less than the strength at night when the search coil was placed in a position *at right angles* to the maximum day position, and where it could, hence, only receive the C component wave.

Furthermore, owing to the constant readjustments in height of the E layer, which take place as the sun's light is withdrawn, the length of the path of the reflected wave is changing and, with it, the phase relations of the A and B waves.

As the condition of phase opposition of A and B approaches, the intensity of signals continues to fall until, at a certain instant, the e.m.f.'s due to A and B are exactly opposite in direction round the frame and (supposing them also to be equal in amplitude) the signal strength will be a minimum. During this period of weakening, the e.m.f. due to the C component has been steadily taking more and more effect, until finally only this e.m.f. remains and the figure eight minima are 90° in error. After passing through the phase opposition period, the resultant of the A and B e.m.f.'s begins to increase to a maximum again, the effect of the C wave is reduced, and the minima return to their normal positions.

On drawing out the scale polar diagrams representing the events which are taking place, it is found that the minima continue to rotate in the same direction beyond the 90° error as the A and B e.m.f.'s begin to get into phase again, so that by the time the cycle is completed, the bearing may be considered to have swung through 180°. The physical meaning of this 180° rotation is not very clear, and the 180° ambiguity of the frame reception, together with the indistinctness of the minima in the neighbourhood of this point, of 90° error, makes it impossible to study closely this part of the cycle.

Owing to the transient nature of the factors which go to produce the above cycle of events, it is not surprising to find that it is not always completed in practice. Very frequently some alteration in the relative amplitudes of the component waves, or in the degree of polarization of the reflected wave, abruptly interrupts the process and may restore the bearing to its normal value again. For this same reason it is practically impossible to reproduce accurately any extended night effects by means of vector and polar diagrams, but the cycle described above, in which the observed bearing rotates through 180° accompanied at one point by a marked diminution in signal intensity, may be shown fairly simply by the vectorial addition of a number of polar diagrams representing the A, B and C component e.m.f.'s.

A Synthetic Night Effect Graph. In calculating the polar ordinates of the diagrams of reception for 14 consecutive phase conditions of the A and B rays, the following assumptions have been made :

A wave and the B component of the reflected wave equal in amplitude.

Reflected wave elliptical, and polarized 30° from vertical.

C component lagging 45° on B component.

The positions of the cosine minima together with the maximum and minimum signal strengths are tabulated below, and the complete diagrams are illustrated in Fig. 186.

The condition of B leading 270° on A is taken first, as this happens to be a condition of zero error :

Phase Difference between A and B.	Rotation of the Fig. 8 Minima.		Signal Strength. Max.	Min.
B leading 270°	0°	180°	1·43	0·58
B ,, 300°	5°	185°	1·75	0·53
B ,, 330°	9°	189°	1·95	0·5
B and A in phase	12°	192°	2·0	0·42
B leading 30°	15°	195°	1·98	0·28
B ,, 60°	18½°	198½°	1·84	0·15
B ,, 90°	22°	202°	1·51	0·0
B ,, 120°	29½°	209½°	1·15	0·28
B ,, 150°	48°	228°	0·75	0·40
B ,, 165°	68½°	248½°	0·63	0·25
B ,, 180°	90°	270°	0·58	0·0
B ,, 195°	107¼°	287¼°	0·59	0·21
B ,, 210°	129½°	309½°	0·66	0·38
B ,, 240°	166°	346°	1·02	0·55

The scale of signal strength is based on a unity value equal to the maximum simple frame intensity of the A wave alone.

Comparison of Theoretical and Experimental Graphs. In Fig. 187 the variation in bearing has been plotted against the phase relation of the A and B component waves, and a close resemblance is found between the resulting curve and the experimental curve of Fig. 183. An interesting point is that the apparent bearing is correct when B leads 270° on A, and it is 90° in error when B leads 180° on A ; that is to say, three-quarters of complete phase cycle later. The apparent bearing then swings through the next 90° in the remaining quarter of a cycle. In the experimental graphs of Fig. 183 and Fig. 185, the same effect is to be noticed to some extent,

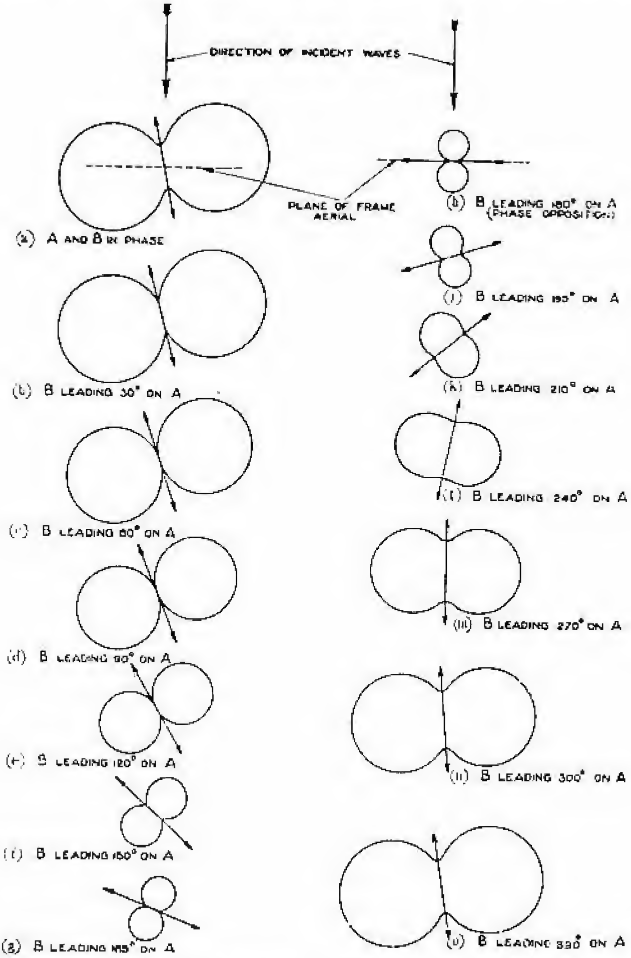


Fig. 186.—Series of Theoretical Polar Diagrams Illustrating the Result of Night Effect on Figure Eight Reception.

namely, a slow variation for the first 90° rotation of the bearing and a rapid swing for the remaining 90°. The change in signal strength with variation in bearing also compares fairly well in Fig. 185 and Fig. 187.

The fact that the minima are sharp in the case of the theoretical diagrams may be accounted for by the fact that a particular case was assumed, for the sake of simplicity, in which the A and B waves were exactly equal ; the result being that at the instant of phase opposition there remained only the small figure eight diagram of the C component field. In practice this would be an exceptional condition, and clearly any residual effect from either the A or B waves would combine with this C diagram and give a diagram in which the minima were very indefinite. The example must only be considered as illustrating the very simplest case, without taking account of the varying relative amplitudes of the A and B component waves, reflection from the earth's surface at the receiver, or any possible secondary effects which are taking place. In reference (3727), however, M. Dieckmann describes some experiments with a continuously rotating frame under night effect conditions, using a cathode ray tube to produce an image of the complete polar diagram. A comparison is made, by Dieckmann, between the calculated results of Fig. 186 and his own experimental results and the resemblance between the two is very close.

Discussion of Fig. 185. Fig. 185 is a typical night effect graph and is worth investigation.

The period of 1 hour 40 minutes over which the observations were made may be divided fairly sharply into four distinct sections as follows :

(*a*) 7.45 to 8.10 p.m.—Complete cycle of variation of apparent bearing, with reduction of signal strength corresponding to the theoretical reasoning stated above.

(*b*) 8.10 to 8.30 p.m.—Gradual displacement of the apparent bearing to 30° error and return to normal.

(*c*) 8.30 to 8.50 p.m.—Bearing swings slowly from positive error to small negative error.

(*d*) 8.50 to 9.10 p.m.—Complete cycle of variation of bearing in same direction as before with reduction of signal strength practically to zero.

Now, the time taken for each of the complete cycles of variation in bearing (*a*) and (*d*) was roughly 20 minutes, and the two intermediate periods of variation were also of the same length, so that we may assume that each of the four periods corresponded to a complete phase cycle of the A and B waves. On the above assumption and knowing the distance between Chelmsford and Clifden to be roughly 740 kilometres and the wave length of Clifden to be 6,000 m., we can find, either by calculation or graphically, the relation between the height of the reflecting layer and the speed at which it is rising. The length of the path of the reflected wave will, of course, have to increase by one complete wave length for each cycle of phase change of A and B.

Throughout the whole series of observations from which the curves in Fig. 183 and Fig. 185 have been chosen, it was noticed that the variations started comparatively abruptly, a short time after sunset, the exact period which elapsed depending on the relative positions of the transmitting and receiving stations. After a period of an hour or so of violent variations in bearing and signal strength, the conditions usually settled down to the normal night character or erratic variations of smaller degree.

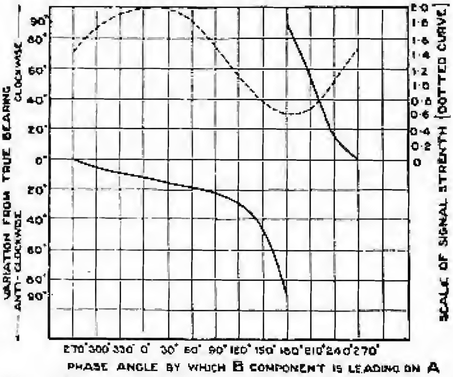


Fig. 187.—Results of Fig. 186 Plotted to show their Resemblance to Fig. 183 and Fig. 185.

Smith-Rose's and Barfield's Investigations. In 1926 R. L. Smith-Rose and R. H. Barfield (Radio Research Board) published an account of experiments carried out with a view to obtaining more conclusive evidence as to the cause of apparent variations in bearing and which established a further confirmation of Eckersley's original theory. In the course of this work a method of using Adcock's aerial system for the elimination of night errors was developed and reference is made in the next chapter to the remarkable success attained by its use.

The paper (2617) is an interesting and valuable one and should be studied for further details. Fig. 188 is reproduced from it and in addition to showing the Adcock aerial results, also illustrates a number of 360° rotations of the apparent bearing of Bournemouth Broadcasting Station as observed at Slough.

The cycle of rotation of the Clifden bearing on 6,000 m. took 20 minutes, whilst the 386 m. Bournemouth wave exhibited more rapid rotations, taking only about four minutes. This would be expected as, on a shorter wave length, the time taken for the complete cycle of interference between the direct and reflected rays would be correspondingly less.

Long Wave Results. On very long waves it is interesting to note that the bearing of the high-power Japanese alternator JAA on 15,250 m. was observed by I. Tanimura in 1930 from a receiving point 148 km. distant. The apparent bearing swung slowly 30° East, back through the correct value and then 30° West and once again to normal in a period of 3 to 4 hours before sunset and this was sometimes followed by a second similar cycle. Irregular variations took place during the night and then the above cycle was repeated, but in the reverse order, before dawn.

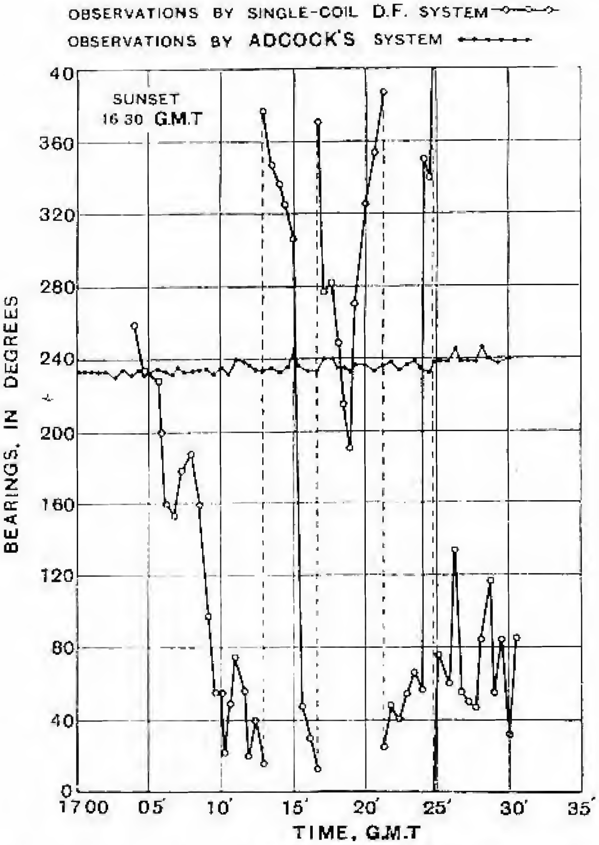


Fig. 188.—Complete 360° Rotation of Apparent Bearing of Bournemouth Broadcasting Station (Jour. I.E.E.).

In this case it is clear that the B ray was never strong enough to oppose the direct ray completely and hence the effect of the C, or error-producing ray, was limited to a 30° swing (3014).

A U.S. Bureau of Standards Test. Experiments carried out to find the extent of night variations in the equi-signal course of the U.S. aircraft beacons have already been mentioned and the beacon system is described in Chapter 12. Among the above tests (3301), H. Diamond describes one made to ascertain whether any causes other than the rotation of the plane of polarization were responsible for night errors.

For this purpose, signals were transmitted alternately on the normal approximately double cosine "equi-signal" arrangement and on a single loop at right angles to the course, the loop being modulated in equal amounts at the two beacon modulation frequencies. In this latter condition, it is clear that there would be reception from the loop along the nominal line of zero radiation, under night effect conditions, but although the signal strength might vary, the equi-signal condition should be maintained on the single loop signal, unless some form of selective audio frequency fading were present.

The results are shown in Fig. 189 where A refers to the crossed loops and B to the single loop, and they tend to confirm that the reflected ray combined with rotation of the plane of polarization was definitely the chief cause, and this was a deciding factor in the adoption of the Adcock type of transmitting aerial in place of the closed B-T loops.

DAY-TIME VARIATIONS IN BEARINGS

Apart from the now well-known periods during which errors may be expected to be present, there is ample evidence that the E layer is effective in producing variations in apparent bearing of medium and long waves during broad daylight.

Wave lengths in the 200 to 500 m. (1,500 to 600 kc.) band are subject to varying degrees of wandering bearing at any time except around mid-day in the summer, whilst Watson Watt (3617) mentions the case of Rugby on 3,846 m. (78 kc.) the bearing of which at Slough, 96 miles distant, has been observed to move through 24° in 51 minutes in the middle of an October afternoon. Hoyt Taylor (2907) in a discussion on a paper by Smith-Rose before the Institution of Radio Engineers, in America (2906), took exception to the expression "night effect" as he maintained that the errors occurred only too often in the daytime.

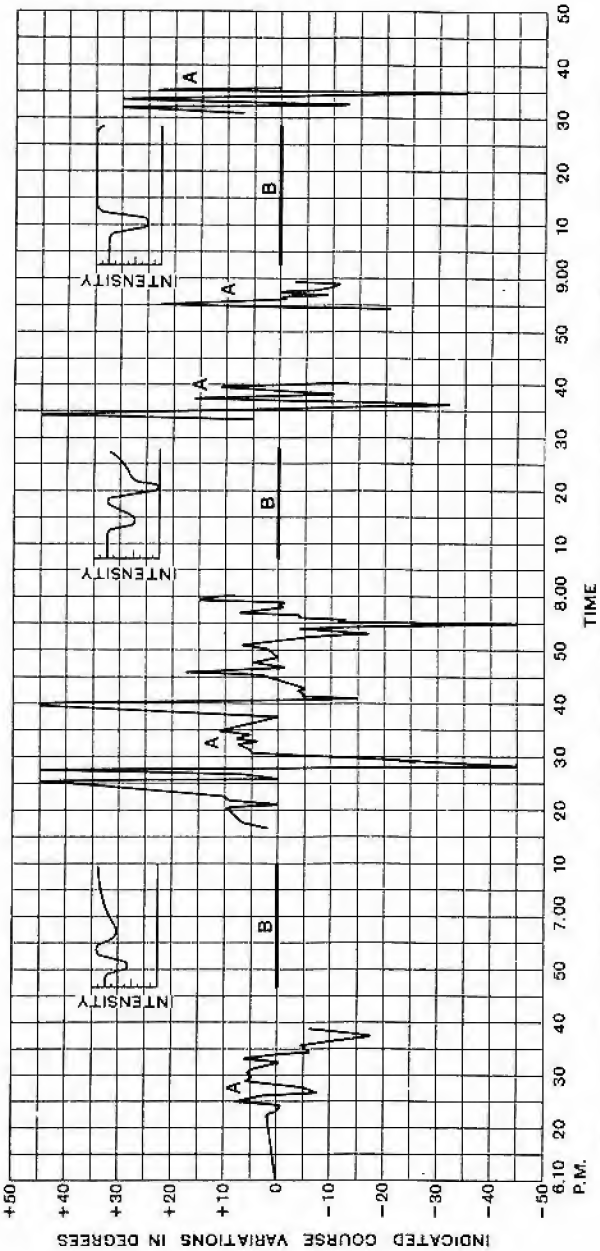


Fig. 189.—Night Effect Test on U.S. Radio Range Equi-Signal Beacons (U.S. Bureau of Standards Journal of Research).

An account of more recent investigations on the daytime variations of very long waves, by Best, Ratcliffe and Wilkes, occurs in (3623).

THE ELIMINATION OF POLARIZATION ERRORS IN BEARINGS

Various methods have been suggested for obtaining correct wireless bearings during periods when the reflected rays have a component of horizontal polarization. Those mentioned below are all effective to a point, but the one that is having the chief commercial application at the present time, is the Adcock aerial.

The Heart-Shaped Diagram. In Chapter 4 it was seen to be possible, by combining the e.m.f.'s induced in a frame and a vertical aerial under certain conditions, to obtain a polar diagram which has only one minimum, and that this minimum lies in the plane of the frame aerial. Since this is the direction in which the wave with a vertical magnetic field also has minimum influence upon a simple frame, a possible method of eliminating night effect is presented.

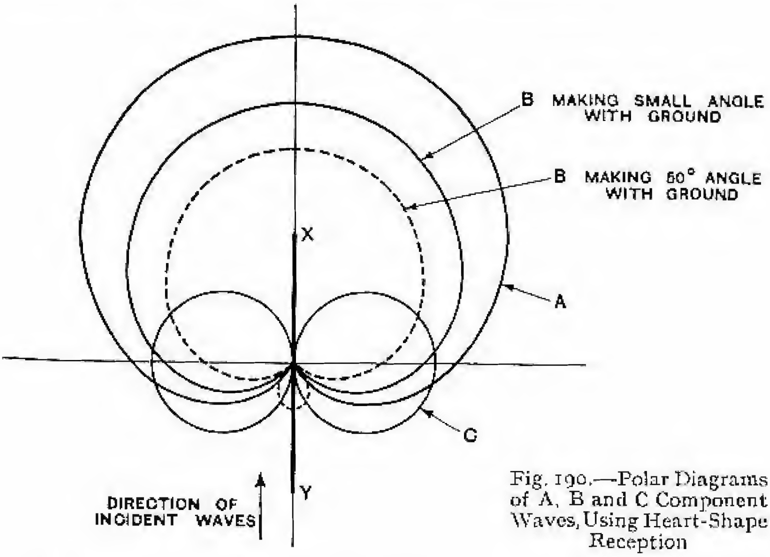

B MAKING SMALL ANGLE WITH GROUND
B MAKING 60° ANGLE WITH GROUND
X
A
C
Y
DIRECTION OF INCIDENT WAVES

Fig. 190.—Polar Diagrams of A, B and C Component Waves, Using Heart-Shape Reception

In Fig. 190 suppose XY to represent a plan view of a frame aerial and the arrow to show the direction of arrival of the three component waves A, B and C from a transmitting station, the aerial having been adapted by means described in Chapter 4 to give a heart-shaped diagram on a normal wave.

The C component cannot be received by the vertical aerial, owing to the fact that its magnetic field is in a vertical plane, and hence the diagram obtained in respect of this wave will be the figure eight diagram C and not a heart-shape. The A wave will produce a normal heart-shape and the B component will also give a heart-shape, as shown in the figure, with the same adjustments as for A provided that the angle which the B and C rays make with the ground is not too great.

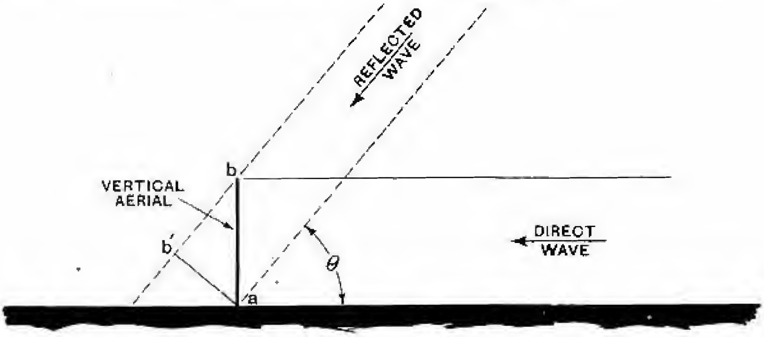


Fig. 191.—Reduction in Induced E.M.F. in Vertical Aerial when Reflected Wave has a Large Angle of Elevation.

If the wave is coming down steeply and the angle of elevation is as shown by θ in Fig. 191, it is clear that the number of magnetic lines of force in the wave which cut the vertical wire will not be proportional to the length $a\ b$, as in the case of the A wave, but will be proportional to $a\ b'$, which is the projection of $a\ b$ at right angles to the direction of arrival of the B wave, and equals $a\ b \cos\theta$. The vertical wire e.m.f. will now not be great enough to give a true balance on B, although it will be correct for A, and the resulting diagram for B, for $\theta = 50°$, will be as shown dotted in Fig. 190, and will have an impure minimum. There is good reason to believe, both from theoretical and experimental evidence, that the angle with the ground, θ, for long and medium waves is rarely sufficiently large to cause any appreciable difficulty in obtaining a heart-shape balance on both the A and B waves, although for short waves the balance is more uncertain and this point is referred to again in Chapter 10. Long-wave directional receiving stations employing the heart-shaped diagram for commercial reception do also experience difficulty in maintaining a balance at times, but under average conditions the effect is uncommon.

Fig. 192 shows the reception in a vertical plane of a combined frame and open aerial which have been adjusted to give a cardioid. The vertical plane illustrated is that which includes the heart minimum and shows that for a wave arriving in the direction of the minimum the reception is hardly enough to upset the cardioid minimum unless the angle with the ground considerably exceeds 30°.

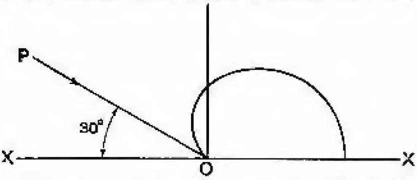


Fig. 192.—Polar Diagram, in Vertical Plane, of Frame and Open Aerial Combined to give Heart-Shape.

Graphical Representation of the Cardioid Diagram under the Influence of Night Effect. For the purpose of comparison with the series of diagrams for the simple frame under night effect conditions, shown in Fig. 186, a similar series has been drawn out to scale for the cardioid reception. The conditions taken are the same as before, namely, the A and B components equal, an elliptical reflected wave polarized 30° from the vertical plane, with the C component lagging 45° on B.

The series is illustrated in Fig. 193, and although a well-defined zero of signal strength is always seen to exist in the plane of the frame in these theoretical graphs, the minimum in practice is difficult to locate accurately owing to it being wider and less well defined than in a normal cosine diagram, combined with extreme asymmetry at times.

Means do exist, in an experimental form, for producing polar diagrams that are symmetrical about a single minimum under all ordinary conditions of night variation, but no simple practical form has yet been devised which will be suitable for commercial D.F. work.

Value of the Heart-Shape Circuit in Detecting Presence of Night Effect. The chief function of the heart-shaped diagram in D.F. remains that of determining "sense" but the lack of symmetry is a valuable warning of the approach of night effect, and affords a method of checking the figure eight results from time to time to ensure that reliance is not being placed on clearly defined but incorrect minima.

Due, however, to the present-day tendency to provide approximately unilateral reception only and not a true cardioid for sense, this testing for night effect can probably be done better on the Quadrature Compensator which, as already mentioned, varies in its adjustment for the best minimum with the degree of reflected ray present in the received signal.

Horizontal Frame. From what has been said on page 67 it will be clear that a wave having vertical magnetic force

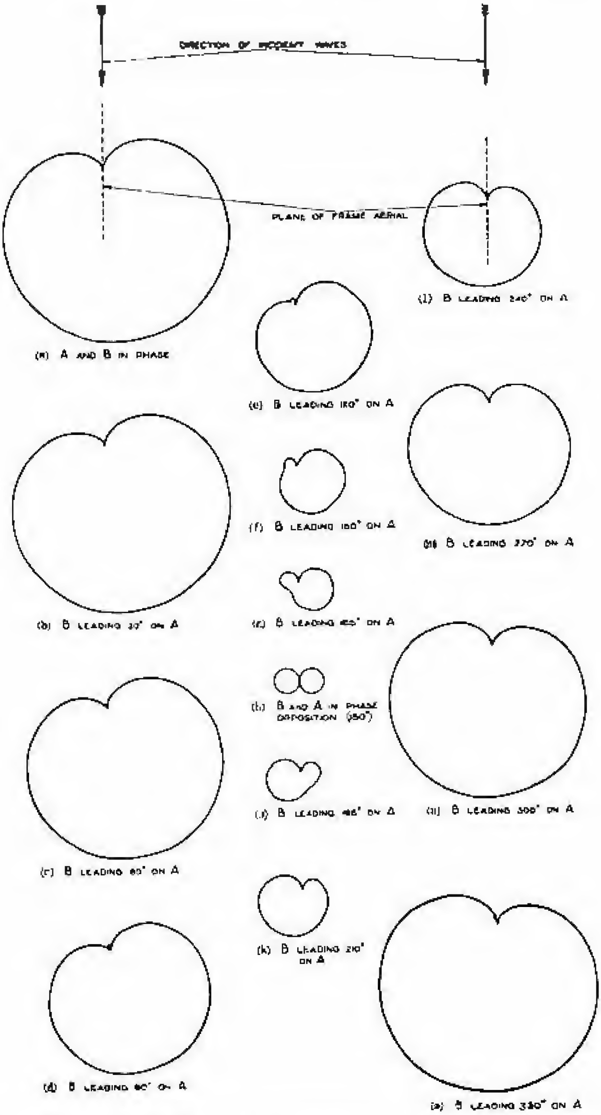


Fig. 193.—Series of Polar Diagrams as in Fig. 186, but using Heart-Shape Reception.

will induce an e.m.f. in a frame which is in a horizontal plane. By a suitable circuit arrangement Eckersley (2105) has balanced the horizontal frame e.m.f. against the e.m.f. which is caused by the cutting of the horizontal limbs of the vertical frame by the magnetic field as in Fig. 50. Some work with a view to confirming these experiments was done later by R. L. Smith-Rose and R. H. Barfield (2506).

By balancing the e.m.f. induced in a horizontal open aerial or frame against the C ray e.m.f. in the vertical loop, the latter e.m.f. may thus be eliminated and a crisp minimum obtained in the correct direction, although there will still be variations in signal strength. There is a fundamental difficulty, however, in applying this method to actual D.F., because the degree of horizontal polarization is constantly changing and is not known. With the D.F. loop in the correct position for a normal cosine minimum, an indefinite minimum may be sharpened under suitable conditions, by a horizontal aerial e.m.f. balance, but by varying the amount of the latter e.m.f. that is applied, crisp minima may also be obtained in other directions when night effect is present. The problem has, in fact, something in common with "D.F. in Three Dimensions," mentioned on page 198.

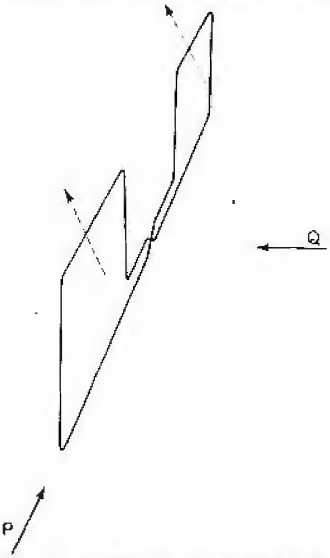


Fig. 194.—Spaced and Opposed Frames

The horizontal aerial may still be used as a test for night effect conditions for, if this aerial coupling has no effect upon the signal received in the vertical loop, it means that no horizontal polarization exists in the indirect ray and hence bearings will be correctly rendered.

Spaced and Opposed Frames. This system appears to have been proposed and tried out independently by C. S. Franklin in England, by T. L. Eckersley in Salonika (2105), and by R. A. Weagant in America (1908). If two frame aerials are connected in opposition, as shown in Fig. 194, and spaced apart an appreciable fraction of a wave length, the system is found to have directional properties which can be used to detect the presence of night effect and also, within certain limitations, to obtain accurate bearings under night effect conditions. Consider, firstly, the vertically polarized wave arriving in the direction P, that is, in the plane of the frames. This wave will induce an e.m.f. in each frame, and since they are connected in opposition, the resulting e.m.f. in the receiving circuits will be that due to the varying intensity of the electromagnetic force in the wave at points spaced some distance apart in the path of the wave; or what has been called (page 62) the "differential e.m.f." of the two frames.

Now consider a wave arriving in the direction Q, that is, at right angles to the plane of the frames. No e.m.f. will be induced by such a wave in either frame, since all the four vertical limbs will be cut simultaneously by the wave front.

If, however, a wave arrives in the same vertical plane as the direction of Q, but making an angle with the ground and also horizontally polarized, then the magnetic flux will cut the frames, as shown by the dotted arrows. Equal e.m.f.'s will be induced in each frame, and since the frames are in opposition there will be no resultant e.m.f. in the receiving circuits. Again, suppose a similar type of wave be arriving in the vertical plane of the frames, then since both the frames and the magnetic field are vertical, there will be no linkage with the frames whatever.

Clearly this aerial system is immune from effect by vertical magnetic fields, the planes of propagation of which are in the "in line" or the broadside directions, but in intermediate directions each frame—and hence also the combined system—is still liable to spurious minima. When broadside to the vertical plane of propagation of the wave, the minimum will however remain pure and hence recognizable as being correct, whilst the spurious minima will exhibit the usual night effect variations.

Important modifications to this aerial system have been made by T. L. Eckersley in its application to short wave direction finding and, for reasons that are explained in the chapters on the Adcock system and Short Wave D.F., he found it necessary to arrange the frames as in Fig. 195 with suitable provision for balancing at the centre.

For vertically polarized rays, with any angle of elevation, along the XX axis the frames are in their position of maximum reception and the e.m.f.'s are balanced out, whilst there can be no reception of horizontal polarization.

For a vertically polarized wave along the YY axis, there is no reception on either frame, whilst the resultant e.m.f. for a horizontally polarized wave will vary with the angle of elevation.

In the broadside direction, along XX, there is thus again a minimum that remains constant for all night effect conditions.

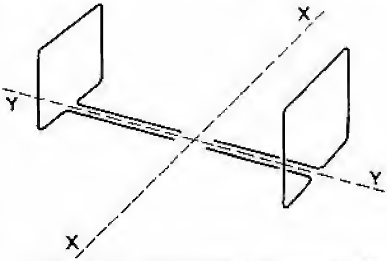


Fig. 195.—Alternative Spaced and Opposed Frame Array.

The Adcock Aerial. In 1919 a patent was granted to F. Adcock for " An Improvement in Means for Determining the Direction of a Distant Source of Electromagnetic Radiation " which consisted of an aerial system in which the effective reception was entirely carried out by spaced vertical aerials, the e.m.f.'s in the horizontal connecting limbs being either cancelled out by balancing or avoided by suitable screening or by other means.

The system in the several forms suggested by the inventor consisted essentially of two pairs of vertical antennæ with their planes at right angles, and with an associated radiogoniometer, but it may be indicated schematically as in Fig. 196 where the lower horizontal member is screened and the active members are the two spaced vertical aerials.

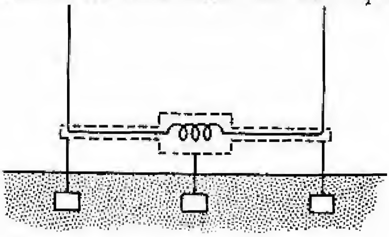


Fig. 196.—Screened Horizontal Members of Adcock Aerial.

Such an aerial, if it could be constructed so as to be really free from all pick-up on the horizontal limb, and also free from any secondary effects due to currents in the screen, etc., must be quite immune from the effect of horizontal electric force and hence from night effect. It will be seen later that such immunity can be closely approached, and the aerial forms, at the time of writing, the most popular type for commercial D.F. installations intended for day and night work.

It is necessary, however, to point out one important disadvantage of an aerial system, the active members of which are vertical, namely that the pick-up for the wanted or vertically polarized components of the wave falls off rapidly as the steepness of the angle of the ray with the ground increases, and it is zero for a vertical ray. On the other hand the unwanted pick-up, namely, that of the horizontally polarized ray, by the supposedly balanced or screened horizontal members of the aerial system remains constant.

Note the difference between this and the spaced loop aerial previously described. In that case, owing to the spaced aerials being closed loops, instead of vertical open antennæ, their individual e.m.f.'s do not vary with the angle of incidence and the proportion of wanted to unwanted pick-up remains high.

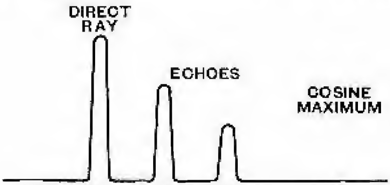


Fig. 197.—Screen Image of Pulse D.F. at Cosine Maximum.

This is not sufficiently serious, in the case of the Adcock, to preclude this aerial from being extremely valuable under suitable conditions—as will be seen in the next chapter—but it is a fundamental advantage of the spaced loops which becomes of paramount importance when dealing with very high angle rays.

The Pulse Direction Finder. The development of the pulse technique, which has been mentioned on page 37, has suggested a somewhat revolutionary system of night-effect-free direction finding, employing the visual separation of the direct ray from the reflected rays on the screen of a cathode ray tube.

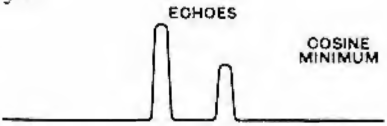


Fig. 198.—Screen Image of Pulse D.F. at Cosine Minimum.

From Fig. 25 it has been seen that when any direct ray reaches the receiver from a pulse transmitter, the oscillograph record indicates this as a clearly defined and narrow formation, whilst echoes from the reflecting layers will appear as shown in Figs. 26 or 27. If, now, the duration of the pulse is made so short that it is always appreciably less than the time taken for the first echo to arrive—as it is in Figs. 26 and 27—a method of direction finding is presented that is free from night effect, for by employing a loop directional aerial and rotating this until the image of the direct ray is reduced to zero—ignoring the echoes—it is known that bearings are being taken only on the vertically polarized radiation.

The appearance of the images on the screen for the condition of cosine maximum will be as in Fig. 197 and as the frame is rotated to the minimum the first or direct ray image will disappear as in Fig. 198, whilst the variation in height of the reflected ray images will depend upon the polarization of their components.

Further details of the method, and its limitations, are dealt with on page 675, together with a description of commercial equipment using this system.

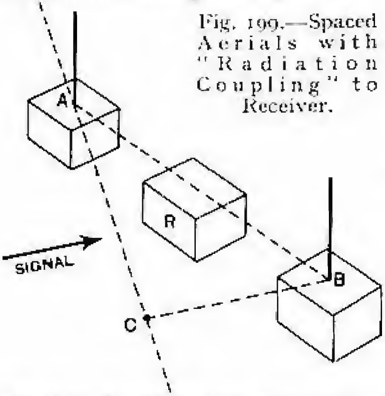


Fig. 199.—Spaced Aerials with "Radiation Coupling" to Receiver.

"Radiation Coupling" of Aerials. In the discussion on R. H. Barfield's paper (3015), a method of eliminating the results of horizontal polarization is suggested by S. B. Smith, which employs spaced vertical aerials with associated receivers that are coupled together by a radiation method instead of physically. Four aerials and a radiogoniometer were mentioned by Smith but the method may perhaps be more easily demonstrated by using two spaced vertical aerials A and B, rotatable about a central receiving point R, as in Fig. 199.

If the arrow be taken to show the direction of travel of the wave, and each aerial has a suitably screened receiver at its base, the problem is to get an indication of the difference of phase of the signals in A and B, which is proportional to the distance CB. If there is no horizontal pick-up, CB will be reduced to zero when the phases of the e.m.f.'s in A and B are identical.

The proposal is to radiate, from R, a carrier frequency which is received by the two aerials and produces a low frequency beat tone in each receiver. These beat tones, which still retain the essential original phase difference CB, are then passed back to R over circuits which are constructed to have negligible pick-up at the radio frequency, and the aerial system is rotated until phase synchronization is attained. In practice, the signals would be arranged to be opposed and would be balanced for zero reception as with a frame.

The method has been tried out but, it is believed, has not had commercial application.

APPLICATION OF ECKERSLEY'S THEORY TO OTHER COMMON TYPES OF NIGHT EFFECT

Land and Sea. When an expanse of sea separates the transmitting and receiving stations, the night variations are usually not so violent as when the waves have to pass the same distance over intervening land. Mountainous country gives rise to very bad errors in bearing at night. This is due to the fact that over sea the attenuation of the direct wave A is small and hence the C component has less effect in distorting the bearing at the same distance, since the amplitude of the resultant of the A and B waves remains fairly large through the cycle of phase relation. On the other hand, over land—and particularly over mountainous country—the attenuation of the direct wave may be considerable, and the conditions described on page 208 may result, in which the C component, during the periods of phase opposition of A and B, is practically the only signal received, with consequent errors. (For definitions of A, B and C rays, see page 205).

Marking and Spacing Wave Discrepancies. An occurrence which is by no means rare in the case of reception from a continuous wave station, which uses slightly different wave lengths for marking and spacing signs, is that the apparent bearings of the signals on the two wave lengths may differ from one another by as much as 30 or 40 degrees. At one moment they may both be approximately correct, but on making observations over a period of, say, half an hour, it will be noticed that first the one and then the other bearing will swing through a considerable angle, accompanied by changes in the definition of the minimum.

Remembering that the phase relations of the A and B waves at a receiving station depend on the transmitted wave length, we can see a possible explanation of this effect. A series of variations similar to those shown in Fig. 186 may be taking place in respect of each of the wave lengths from the station, but owing to the fact that the distance between the receiving and transmitting stations is not an exact multiple of both wave lengths the two cycles of phase relations are not in step with one another, and so one bearing may appear in error whilst the other is correct, and either or both may have indefinite minima. The series of changes could be heard any evening when night effect was prevalent on listening to and noting the bearings of a continuous wave station when marking and spacing waves were in common use.

Maximum and Minimum Distance Between Transmitter and Receiver for Night Effect. Since the height of the E layer may be as much as 120 km., it might be expected that night effect would not be experienced over short distances, since the reflected wave would have to travel very much greater distances than the direct wave and hence would suffer considerable attenuation, so that its effect would be reduced. Actually this is found to be the case, and at distances less than about 25 km. variations are rarely noticed to any appreciable extent. Another and still more probable cause is that in the case of stations close together, the reflected wave must meet the reflecting surface almost at right angles, and hence some of the energy passes through the surface instead of being reflected and is so lost to the receiving station.

In America, errors are encountered at shorter distances than in England and Hoyt Taylor mentions cases of errors of 30° at less than 10 km. (2907) on transmitters operating in the American medium-wave broadcast band. Smith-Rose suggests, as a possible cause of this, that the lower ground conductivity in the United States leads to a greater attenuation of the direct ray, and as a consequence the B ray is able to cancel the A ray at storter distances, enabling the C ray to take effect sooner.

Owing to the direct ray suffering greater attenuation on medium than on very long waves, night effect tends to occur at shorter distances on the former although this may be counteracted by the greater transparency of the E layer for the shorter waves with decreasing angles of incidence.

With regard to the variations in bearing of stations at greater distances, opinions seem to differ somewhat, but observers are fairly unanimous that at distances of some thousands of miles the errors encountered are usually of a few degrees only.

It is reasonable to suppose that polarization errors reach a maximum at a distance from the transmitter such that the A and B rays are equal in amplitude, for there is then the greatest chance of their cancelling one another during phase opposition. Seaplanes making long-distance ocean flights are reported, when using a medium wave length, to have experienced such a condition at about 300 to 500 miles, beyond which the accuracy of bearings improved and was good enough for navigational purposes.

Eckersley states (2510) that throughout a long series of observations made by Tremellen, in various parts of the world, on stations at distances of the order of 7,000 to 10,000 miles, bearings at night were almost invariably correct and free from distortion. He goes on to say: "Sufficient explanation of this may be found in the fact that in order that signals may arrive at 'B'* say, with a high angle of incidence, the ray must proceed by many reflections, and the higher the angle of incidence the greater must be the number of reflections. As a considerable amount of energy is lost at each reflection, it is probable that the high angle rays disappear after a few reflections and leave the normal ray undisturbed."

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* This refers to a diagram very similar to Fig. 182.

Spark, I.C.W., Modulated and Continuous Waves. It has already been mentioned that violent night variations are more prevalent on continuous waves than on damped waves, and according to the Eckersley theory one would expect this to be the case for the following reason. The analysis of a deeply modulated wave shows that the wave form is composed of a number of component waves of varying lengths, and on the assumption that one, at any rate, of the causes of distortion of bearing is due to the varying phase relations of the A and B waves, it will be realised that only in exceptional cases can the condition of phase opposition of the direct and reflected waves exist for more than a small proportion of the total number of component waves. The presence of night effect conditions can usually be recognised in the case of damped signals, since a sharp displaced minimum is rare.

With the replacement of spark transmitters by I.C.W. or Modulated C.W. ones, their performance with regard to night effect has been somewhat degraded, but remains appreciably better than when pure C.W. is used. This is one of the reasons why M.C.W. is used for marine beacon transmitters, though the main reason for its use remains that of ease of identification of beacons by their respective modulation frequencies.

Change in Character of Note of a Modulated Signal. In the case of signals with a deeply and very roughly modulated note, indicating a wide modulation spectrum, a curious change in the character of the note is observable as the D.F. aerial is swung through the direction of cosine minimum during bad night effect conditions. This was more common when spark transmitters were in general use (2001) and becomes less distinguishable as the modulation becomes lighter and more pure. In extreme cases this change may be so marked as to make it difficult to obtain a bearing since the minimum itself is ill defined and the taking of swing bearings entails the matching of two notes that are very different in character.

The following is a suggestion which has been put forward to explain the effect.

When night effect is present, the telephone signals are the result of the three component e.m.f.'s, due to the A, B and C waves, of which A and B have been seen to produce the normal figure eight polar curve, which changes sign as the plane of the frame moves through the direction at right angles to that from which the signals are arriving. The e.m.f. in the frame due to the C component, however, does not change sign at this point, but is, on the other hand, at its maximum amplitude. Exactly at the minimum point, therefore, the signals are due principally to the C wave, and the note is moderately clear. At a considerable angular distance on either side of the minimum the effect of the A and B waves together is much greater than that of the C wave, and they give a clear note. At the positions, however, on either side of the minimum where the A, B and C components all have effects on the signals comparable with one another, the note may be reduced to merely a hiss, and the reversal of the sign of the A and B waves will result in the combined wave form due to the three components being sufficiently different on either side of the minimum to change the character of the note.

The effect has the advantage of being an unfailing warning of pronounced night effect.

OTHER SUGGESTED CAUSES OF VARIATION IN APPARENT BEARINGS.

The Weather. Claims have been put forward by a small number of writers that errors during both day and night bear some relation to the weather. P. Duckert (2804, 2820 and 2919) has concluded from observation over a number of years that daytime errors always and only occur when an unstable meteorological condition exists between the transmitter and receiver. He also mentions humidity and the wind as factors. In extenuation of these claims he says that whilst sunset variations in bearing are always accompanied by corresponding changes in signal strength, the daytime errors occur with constant signal strength, and hence are presumably not due to ray interference.

Fog. Errors of a more constant nature and probably akin to Coast Refraction have been ascribed to banks of fog encountered at sea. Smith-Rose however, in a report on very extensive observations, carried out at times during local fog and also when fog was widely spread over England and neighbouring parts of Europe, states that no effects could ever be ascribed to this cause (2722). Rothé also obtained negative results regarding the effect of fog. (2109).

The Moon. K. Stoye (2226) states that he has observed the accuracy of bearings to be affected by moonrise and he also attributes errors to the direction of the wind.

Magnetic Storms. B. Dull (3207), after extensive observations of night effect in Northern latitudes, relates sunspots, terrestrial magnetic disturbances and aurora to night errors in bearings.

It is generally accepted now that the unusual electronic and corpuscular bombardment from the sun is responsible for the most serious of the short-wave " fade-out " conditions and possibly for the daytime variations on long waves, but Dull appears to attribute normal night effect to this form of electro-invasion.

LATERAL DEVIATION

Dating from early records of errors in bearings, suggestions have been made that an electromagnetic wave, although undisturbed by outside influences, might not travel along the great circle path between the transmitter and receiver but, having taken some other circular route, might arrive from an unusual direction. As explained on page 258, when dealing with the great circle path, the above state of affairs is inconceivable when the principle of propagation in the plane of the great circle is understood, and the undisturbed path must be along the short or long great circle route.

Tilted Layer Theory. Another suggested cause of lateral deviation is that a tilted reflecting layer may exist as shown in an exaggerated form in Fig. 200. Such a layer might direct a ray towards the receiver from almost any direction and so account for large errors.

T. L. Eckersley (2105) suggested a tilted layer as a possible source of horizontal electric force in the reflected rays and it is also referred to by Watson Watt (3617).

1926 Observations. Barfield and Smith-Rose in their work (2617) which has been referred to on page 212, discussed Lateral Deviation of waves as a possible cause of the residual errors of plus and minus 7° which they were unable to eliminate with the Adcock aerial. They showed, however, as had been pointed out by Heiligtag (2302), that given suitable phase relations between the ground ray and the reflected and deviated ray, the error in bearing due to the combination of these rays may greatly exceed the actual lateral deviation.

Eventually they decided that there was not enough evidence to establish the presence of lateral deviation except possibly in the ground ray due to obstructions.

Later Work. The general acceptance of the theory of ray interference combined with horizontal polarization, allayed somewhat the desire to find other sources of error, and particularly as a commercial form of D.F. free from night error did not exist, the necessity for clearing up additional errors was not very urgent.

With increasing knowledge of the mechanism of wave propagation and with the gradual perfecting of the Adcock aerial the residual errors have taken on a new importance, and in recent years the study of lateral deviation has again been active.

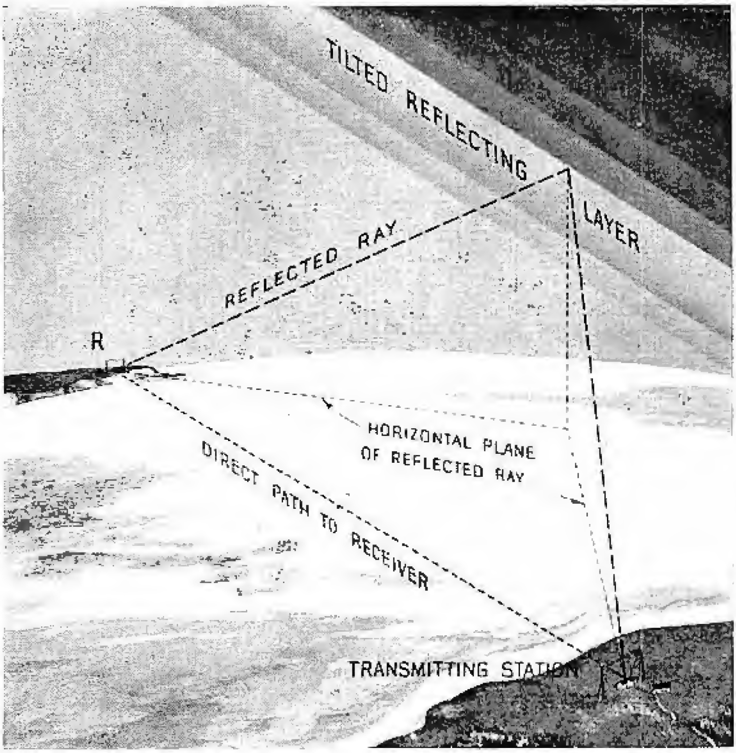

Fig. 200.—Indirect Ray Not Travelling in Vertical Plane of Direct Ray and Reflected from Oblique Reflecting Surface.

J. A. Ratcliffe and J. L. Pawsey have published data (3311) on the subject, and mention that on wave lengths of the order of 200 to 500 metres, deviations of as much as 20° were noted at distances from the transmitter of 200 km. or less. Information on the subject has also appeared in the reports of the Radio Research Board of Australia.

On short waves, Barfield (3015) noted that, within the skip distance, errors were the same on both closed loop and Adcock aerials. Had the errors been due to polarization, the Adcock errors would have been appreciably less, and he inferred from this that the errors were due to the deviation of the waves in the ionosphere. This, however, belongs rather to the phenomenon of scattering than to lateral deviation in its usually accepted sense.

A reference to lateral deviation made by R. A. Watson Watt (3615) is mentioned on page 247.

The Cardioid and Lateral Deviation. In their observations on 6,000 metre signals at a distance of 550 miles (2112), Wright and Smith noted that there was always a zero signal condition at the cardioid minimum in spite of cosine diagram errors of 90° due to polarization. This seems to discount the existence of lateral deviation under these particular receiving conditions.

CHAPTER 7

THE ADCOCK AERIAL SYSTEM (LONG AND MEDIUM WAVE LENGTHS)

Introduction. It has been seen in Chapter 1 that in the early types of direction finders such as those of J. Stone Stone and the original Bellini-Tosi arrangement, the tops of the vertical aerials were not connected by a horizontal member, these D.F.s simply using open aerials spaced a fraction of a wave length apart. The e.m.f.'s in the aerial were summed up in a separate circuit instead of in the loop itself. The addition of the horizontal limbs and the conversion of the aerial to a closed loop simplified the circuit, but had the effect —not realised at the time—of laying in store a source of increased troubles due to polarization errors.

Adcock recognized from the experiments made with loop aerials, on the downcoming waves from aeroplanes, already mentioned on page 192, that the errors with the closed loops were due to the reception, by the horizontal parts of the loop, of the horizontally polarized component of the wave radiated from the trailing aerial of the aeroplane. He therefore proposed an aerial in which the active members were spaced vertical wires and in which the horizontal limbs were disposed in such a way that either no e.m.f. could be induced in them, or alternatively, if it were, that it should be balanced out so as to have no effect upon the received signal.

Logically, therefore, the Adcock system should come under the heading of spaced aerials, before the chapter on the frame aerial, but it is difficult to treat the subject before studying the more conventional circuits that have been developed in connection with the closed loop. Furthermore the Adcock aerial necessitates a knowledge of the technique of the Bellini-Tosi system, whilst familiarity with the serious nature of night variations and polarization error, which have now been dealt with, again lends added interest to the study of the means for their elimination. Much of what is said in this chapter applies to the short-wave Adcock aerial, but the details of this must be left until the principles of short-wave D.F. have been considered in Chapter 10.

That serious difficulties were to be anticipated in getting rid of the pick-up by the horizontal members is shown by the precautions that Adcock suggested, and in spite of recent attempts to simplify the system, it still seems that his original ideas were among the most effective.

Throughout the chapter the coil at the centre of the horizontal limb is at times referred to as though it were a coupling coil to a receiver and at other times as though it were the field coil of a radiogoniometer. It will be remembered that so long as the spacing between a pair of vertical aerials is small compared to the wave length, their differential e.m.f. for varying horizontal angles of incidence follows approximately a cosine law and two such pairs of aerials may be used with a radiogoniometer. If the spacing be large enough to cause errors, a correction chart can be used. Alternatively a rotating aerial system can be employed.

TYPES OF ADCOCK AERIAL

The several ways in which the unwanted reception by the horizontal limbs of the aerial may be reduced or altogether eliminated are briefly examined below, and in most cases the value of the Standard Wave Error, mentioned on page 196, is given. These values were calculated and measured by R. H. Barfield (Radio Research Board) in connection with an extensive programme of work on the Adcock aerial (3504), and give a measure of the relative efficiency of the aerial in its elimination of polarization error on the wave length for which the system is adjusted. In this respect the standard wave error is a useful measure of performance but it cannot be used as a sole criterion of the commercial value of an aerial, as will be seen later.

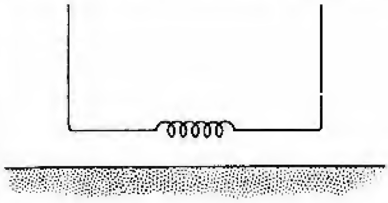

Fig. 201.—The Simple "U" Aerial

For the sake of comparison, it should be noted that the standard wave error of a loop aerial is 35°.

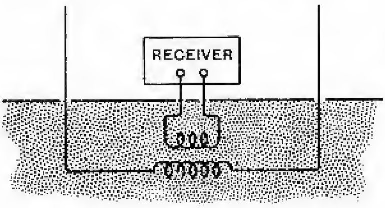

Fig. 202.—The Buried "U" Aerial.

It is somewhat more convenient to study the Adcock aerial principle from the standpoint of electric force rather than flux linkage, as was done in the case of the loop, and this method will be adopted unless otherwise stated in any particular case.

THE SIMPLE "U" TYPE

The "U" aerial is shown in Fig. 201, and if it could be used with the lower member very close to or below the surface of a perfectly conducting earth, as suggested in Fig. 202, the horizontal force in the vicinity could be reduced to zero and complete immunity obtained from the effects of horizontal polarization. In practice, such conditions can rarely be approached and, for an aerial of suitable dimensions for the wave length on which it works and for ground of normal conductivity in England, there is a residual calculated standard wave error of 12°.

The simple "U" type is accordingly not used in commercial D.F. work.

THE SHIELDED "U" TYPE

The screened or shielded form is a natural outcome of the effort to reduce the pick-up on the horizontal member. It is illustrated in Fig. 203 enclosed in a metal tube but, as foreseen by Adcock (discussion on 3015), it is found to have disappointing results. The insulated tube will have e.m.f.'s and associated currents produced in it, and the charges that accumulate at the ends will produce lines of electric force as indicated by the dotted lines. These lines of force have vertical components in the neighbourhood of the vertical aerials and so couple the horizontal and vertical members, with consequent errors.

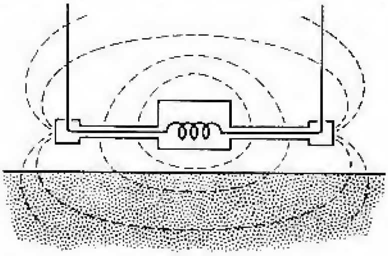

Fig. 203.—The Shielded "U" Aerial Showing Screen Radiation.

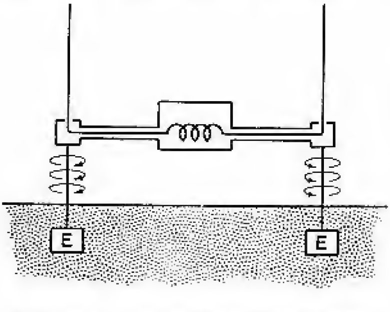

Fig. 204.—The Shielded "U" Aerial with Current in Earthing Wires.

Earth Connection of Shield. The connection of the extremities of the shield to buried earth plates, as in Fig. 204, reduces the charges that accumulate but introduces a new source of trouble since the shield, earth connections and the earth now form an untuned loop that is energized by the horizontal electric force in the wave. The shield itself does not, in this case, behave

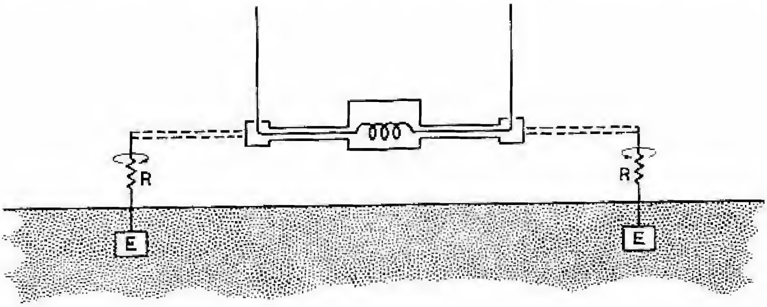

Fig. 205.—The Shielded "U" Aerial with Extended Shield and Terminating Impedances in Earth Wires.

as in Fig. 203 to the same extent, but the field from the vertical earthing connection as shown by the arrows, is coupled with the vertical members of the aerial (3017, 3110).

Extended Horizontal Shielding. The next step is to remove the offending earth connection to such a distance from the aerial that the coupling to the vertical member is very small, and at the same time to reduce, still further, the charges that tend to collect on the shield. Fig. 205 shows the shielding tube extended and terminated through resistances.

The purpose of the tube extension is to avoid discontinuities in the electrical constants of the conductor leading out to the resistance, which would occur if the tube were stopped and a wire extended to the resistance. By thus extending the tube and making the resistance of R equal to the surge impedance (page 173) of the tube to earth, there should be produced the same electrical effect as if an infinitely long tube were used. In this case the current gradient along the tube is zero, and charges and reflection points are theoretically non-existent.

THE BURIED "U" TYPE*

In practice, the above scheme is not very effective and it is found better to bury as much as possible of the shielding system to a depth of 3 to 6 feet as in Fig. 206. It should be emphasized, however, that the burying of cables or feeder tubes to a distance of a few feet does not by any means stop the production of stray currents in them. In order to do this efficiently the soil conductivity would have to be greater than can ever be hoped for, and, under the receiving conditions already mentioned with respect to the simple "U" type aerial, a standard wave error of 6° to 7° remains. The definite advantage of even 3 to 6 feet in normal good conductivity soil makes it worth while, however, and particularly when done in conjunction with an extended earth system in which conductors are taken out to earth plates some hundred feet or so beyond the vertical aerial as in Fig. 207.

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* See note on nomenclature on page 254.

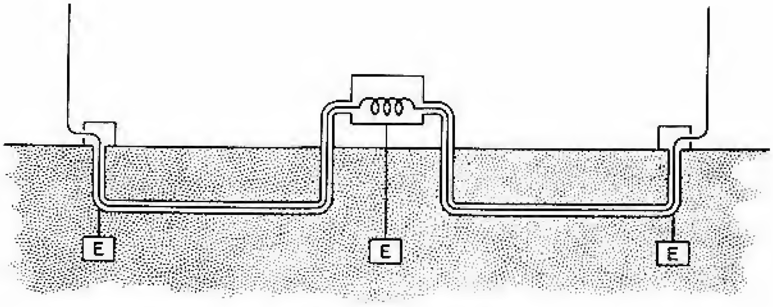


Fig. 206.—The Buried "U" Aerial.

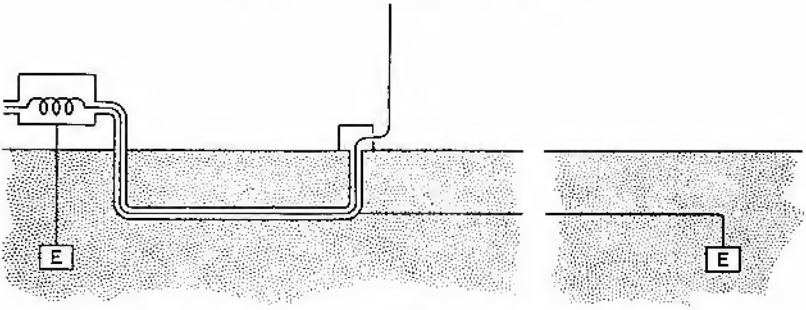


Fig. 207.—The Buried "U" Aerial with Extended Earth Wires.

Results of Unequal Effective Height of Buried "U" Type Aerials. In Fig. 59 was shown the vector diagram for the e.m.f. induced in a frame aerial by a vertically polarized wave, for various angles of horizontal incidence. This may equally well apply to a pair of spaced aerials of the "buried U" type of Adcock system and it is important to notice the effect produced if the vertical aerials are of unequal effective height.

First consider the case of aerials of equal height as illustrated in Fig. 208. As before, ϕ is the spacing between the aerials and θ the angle between the vertical plane of propagation of the incoming wave and the plane containing the aerials. E_a and E_b are the e.m.f.'s in the aerials *a* and *b*, and E_b is reversed since the two e.m.f.'s act in opposition in the aerial coupling

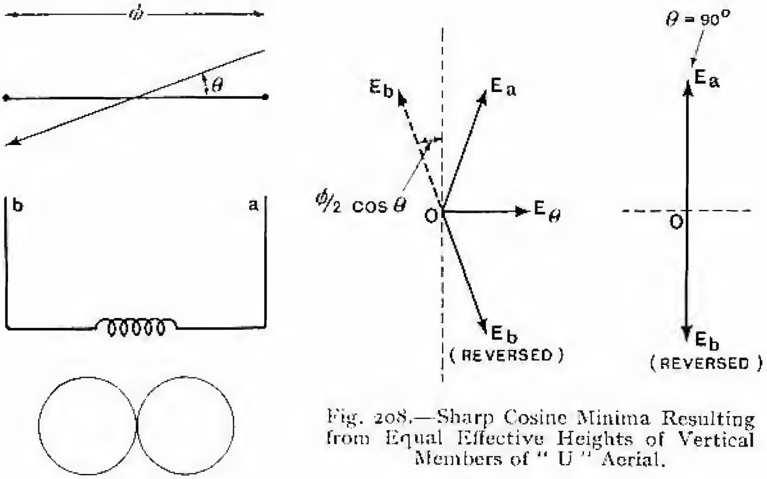


Fig. 208.—Sharp Cosine Minima Resulting from Equal Effective Heights of Vertical Members of " U " Aerial.

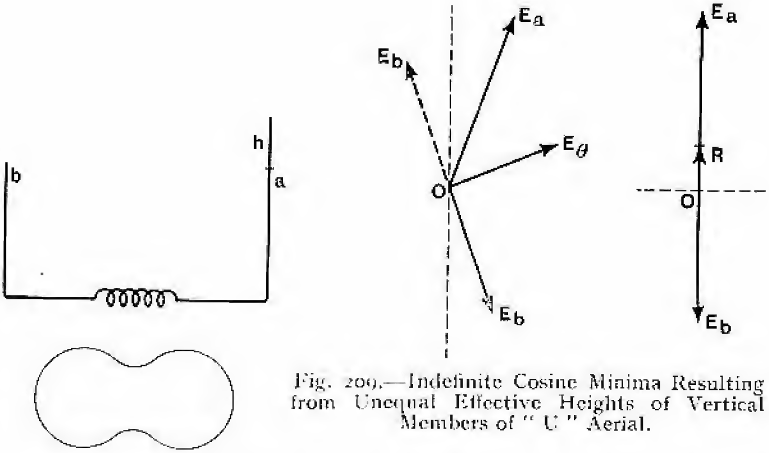


Fig. 209.—Indefinite Cosine Minima Resulting from Unequal Effective Heights of Vertical Members of " U " Aerial.

coil. E_θ is the resultant e.m.f. for the given horizontal angle of incidence.

As the angle θ increases to a right angle, cos θ approaches zero and the two vectors E_b and E_a become coincident, as shown in the right hand vector diagram, whilst their differential sum E_θ disappears and this gives the perfect cosine diagram as illustrated.

Now consider what happens if E_a is greater than E_b by the amount proportional to h in Fig. 209. As θ approaches 90°, the resultant of E_a and E_b swings round into line with E_a where it remains as a small residual e.m.f. at right angles to the normal position for the resultant, and produces the impure minimum of the diagram.

Had the resultant been in phase with, or in phase opposition to, the normal resultant E_θ of Fig. 208, then although there would still have been a signal in the normal direction of the minimum, this could have been reduced to zero by a change in the amplitude of the signal e.m.f.—by moving the search coil slightly away from the correct bearing, for instance—and would have produced the familiar distorted diagram of Fig. 52, which has been seen to result from antenna effect.

The foregoing is dealt with quantitatively by R. H. Barfield and W. Ross in (3708).

However much care be taken in the choice of a site and in the erection of the aerials there is always a fear of unequal height among the four open aerials, and a zero cleaning circuit may be adapted to correct the residual quadrature e.m.f. that is caused. For this purpose an auxiliary aerial is suspended at the centre of the system and has in circuit a condenser and a small variable coupling to the search coil circuit. By ensuring that the auxiliary aerial is well below tune point and low damped, it should have a leading current, and by adjustment of the coupling to the search coil the normal sharpening of one of the minima of the cosine diagram can be obtained (page 91).

In general the receiving circuits are much the same as for the ordinary B-T D.F. receiver, but in the Marconi-Adcock model D.F.G. 10 receiver, which is designed for use with either aerial system, considerable care is taken to retain as much symmetry as possible in the search coil circuit as illustrated in Fig. 210.

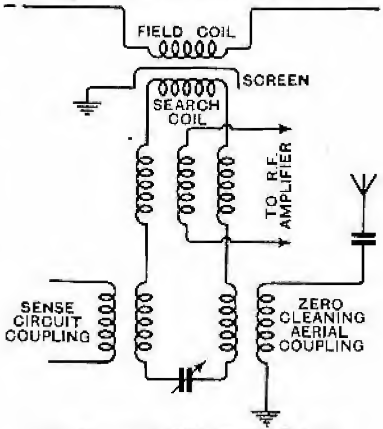


Fig. 210.—Symmetry of Search Coil Circuit.

Test Results with Buried "U" Type. As this form of aerial is the one at present standardized by the Marconi Company and is described in further detail in Chapters 9 and 10, the following test results are of interest. Further reference is made to them on page 245.

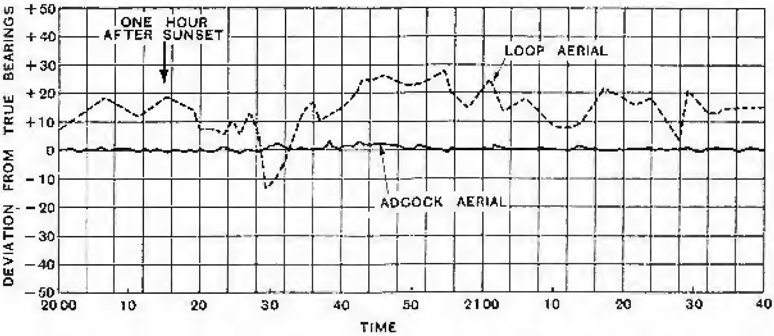


Fig. 211.—Comparative Tests of Buried "U" Adcock and Loop Aerials. Example of Small Variations (Marconi Review).

In October, 1934, S. B. Smith gave the results of the Marconi Company's tests carried out during the previous two years with the buried U type of aerial. The graphs of Fig. 211, 212 and 213 are taken from a large number of test programmes and represent average "good," "medium" and "bad" conditions, the tests in question including altogether some thousands of bearings (3416).

The complete performance is summarized in the graph of Fig. 221 which is placed on page 246 for comparison with Fig. 220, to be referred to later. Fig. 221 shows percentages of observations plotted against degrees of error. It will be seen, for instance, that 30 % of the observations had errors of not more than 1°, 20 % not more than 2°, 7 % not more than 3°, whilst 0·1 % or 1 in 1,000 had an error of 17°.

These bearings were all taken on Kalundborg (1,261 m.) from a receiving station near Chelmsford, Essex, signals having a high field strength and also a mean night intensity of five times the day value—due chiefly to indirect ray signals. As would be expected, the bearings exhibited violent variations on a closed loop D.F. and the receiving conditions were considered to represent fairly closely those of difficult aircraft to ground station working.

When considering the practical aspects of the buried U Adcock installation in Chapter 9, it will be found that the obstacles in the way of finding a perfect site are very

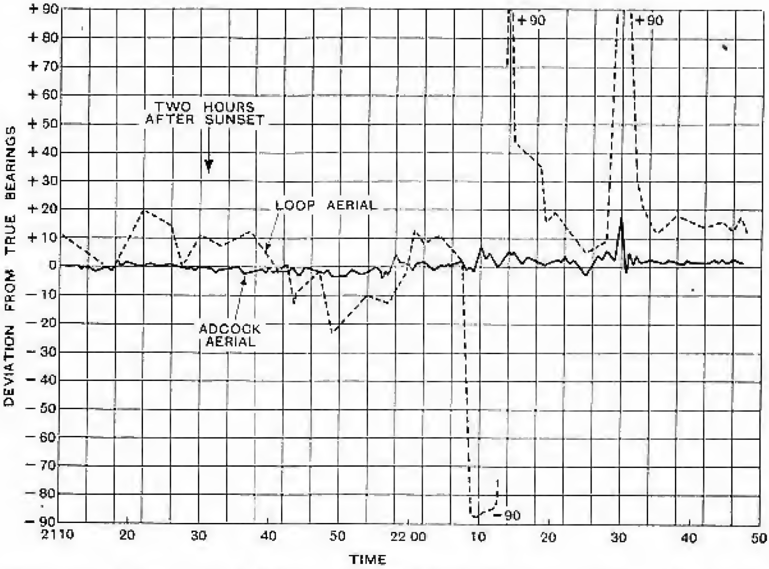


Fig. 212.—As Fig. 211, but Example of Medium Variations (Marconi Review).

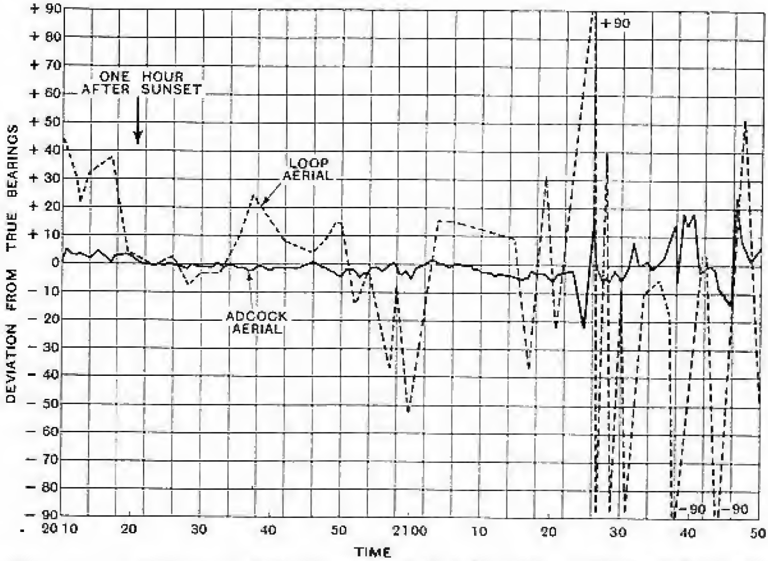


Fig. 213.—As Fig. 211, but Example of Bad Variations (Marconi Review).

considerable, and go a long way towards preventing the complete solution of night errors. Under reasonably good conditions, however, judging from the above results, it should be possible to obtain 92% of bearings with an error of not more than 3°, although the remaining 8% may contain errors up to 15° and 20°.

Although at first sight this seems to point to a failure of the system owing to the introduction of an element of doubt into all the bearings, it must be remembered that the experienced telegraphist will be able to tell, by various well-known indications, when an undue amount of horizontal polarization is present and will know when to discount bearings taken. By this means the value of the installation for navigational purposes may be made to approach much more closely to the ideal than would be imagined from a first perusal of the figures, and in any case it should be observed that during the three nights shown in the graphs, the closed loop D.F. was almost useless throughout.

THE EARTH-CONNECTED "H" TYPE

Resuming the survey of the various forms that the Adcock aerial may take, another form of construction is reached which also involves direct earth connection, namely the earthed "H" type which was included by Adcock in his patent and is illustrated in Fig. 214.

Referring to Fig. 45, assume that the instantaneous position of the aerial in the path of the wave is the same as that of the loop B. The reception of the system will, as in the case of the loop, be the result of the differential action of the e.m.f.'s in the two vertical limbs and, in the condition specified, we can draw arrows to represent these e.m.f.'s "up" in the left-hand aerial and "down" in the right-hand one. For the other positions in the path of the wave, the reception will still be due to the differential e.m.f.

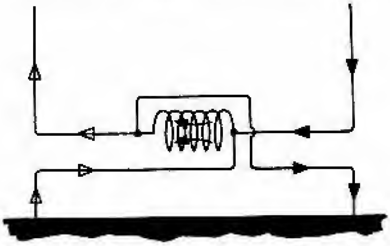


Fig. 214.—Balanced Currents in Horizontal Members of Earth Connected "H" Aerial.

Tracing out these directions of flow of current in the system, the two effects are seen to be additive in the receiving coil, but to be in opposition during their passage along the horizontal limbs. For the same reason any effects produced in the horizontal limbs by direct pick-up will cancel out in the receiving coil. This, however, is only true when the system is completely balanced and since the lower ends of the vertical aerials are connected to earth, whilst the upper ends are open, this necessary condition does not exist. On the contrary, the lower half of the system forms, with the earth connection, a loop of very different electrical constants from those of the upper U-shaped portion; the currents in the two halves are likewise different and an out-of-balance current flows in the receiving coil as shown by the two different types of arrowhead in Fig. 215, with consequent errors.

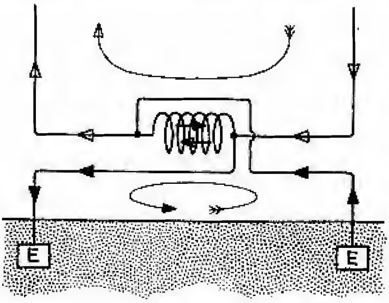


Fig. 215.—Loop Effect of Lower Part of Earth Connected "H" Aerial.

Screening the horizontal portion with a metal tube will completely prevent pick-up on the horizontal members, but still permits coupling between the screen and the vertical aerial, as in the screened U type, so that the asymmetry and errors remain.

THE ELEVATED "H" TYPE

In this case, shielding and earthing are abandoned and a process of balancing is used. The aerial is formed of spaced dipoles, connected to the radiogoniometer in the same way as before, but the whole array is raised sufficiently high above the ground to avoid it upsetting the symmetry of the upper and lower halves of the system.

For the earth's effect to be entirely negligible the method would be impracticable on medium wave lengths

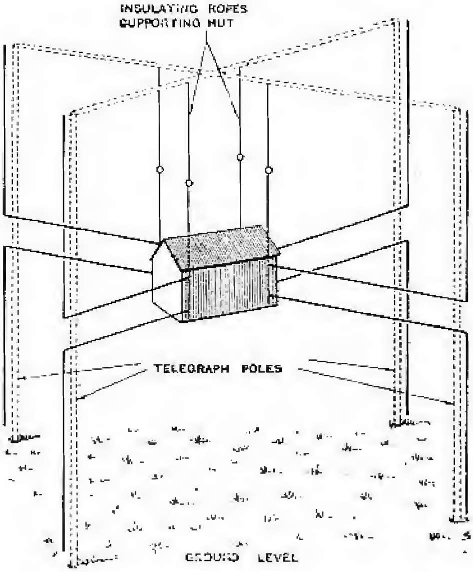


Fig. 216.—The Elevated "H" Aerial (Jour. I.E.E.)

but in a series of tests by R. L. Smith-Rose and R. H. Barfield (2617), mentioned on page 212, a remarkable conquest of polarization errors was achieved on medium wave lengths with the hut at a height of 20 feet as shown in Fig. 216. The graph of Fig. 188 showed some of the results obtained, and although a series of apparent 360° rotations of the bearing occurred on the closed loop, the maximum error with the Adcock was 14° and clearly much less than this in the Bournemouth case illustrated.

It is inconvenient to check the effect of raising the aerial to greater heights when using medium wave lengths, but it has been tried using short waves (3504), and confirms that the residual error steadily decreases as the height increases.

Balance may also be restored by artificial methods. Keeping the aerial near to the ground, the shortening of the lower halves of the dipoles equalizes the capacity to earth of the upper and lower halves and reduces the polarization error to zero, or if carried too far produces errors in the opposite sense. It is, however, an unsuitable method since the balance does not hold for changes of wave length.

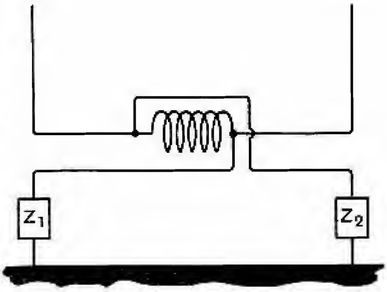


Fig. 217.—The Balanced "H" Aerial.

The standard wave error for convenient constructions of the elevated "H" aerial, with no artificial balancing, is given as being of the order of 4° on 30 m., 3° on 300 m. and 4° to 8° on 1,000 m.

THE BALANCED TYPE

The inconvenience of having the receiving building at the centre of the aerial on medium wave lengths in the above case may be avoided by dispensing with the lower halves of the dipoles and replacing each by a balancing network, as in Fig. 217. Simple condensers have been seen to be unsuitable over a range of frequency and, for flexibility in this respect, the impedances must be complex ones composed of inductance, capacity and resistance, and even then there will be a possible source of residual error owing to the balancing impedances being "lumped" whilst those of the aerial are distributed.

The fundamental difficulty still remains, however, that the current distribution in the upper and lower halves of the aerial is not symmetrical, so that the e.m.f.'s induced in the horizontal members will produce unequal effects in the upper and lower halves. (See page 57 under Effective Height).

The standard wave error for the final arrangement was calculated as 6° and the experimental figure was 8°.

THE COUPLED TYPE

A further, and what has proved to be an effective, method of reducing pick-up in the horizontal members is that of rendering their impedance high to any but the circulating currents due to the e.m.f.'s in the vertical limbs. Adcock's suggestion in this case was the insertion in the horizontal limbs of magnetically coupled circuits in which the capacity of the transformer windings is small. The method will be seen to be

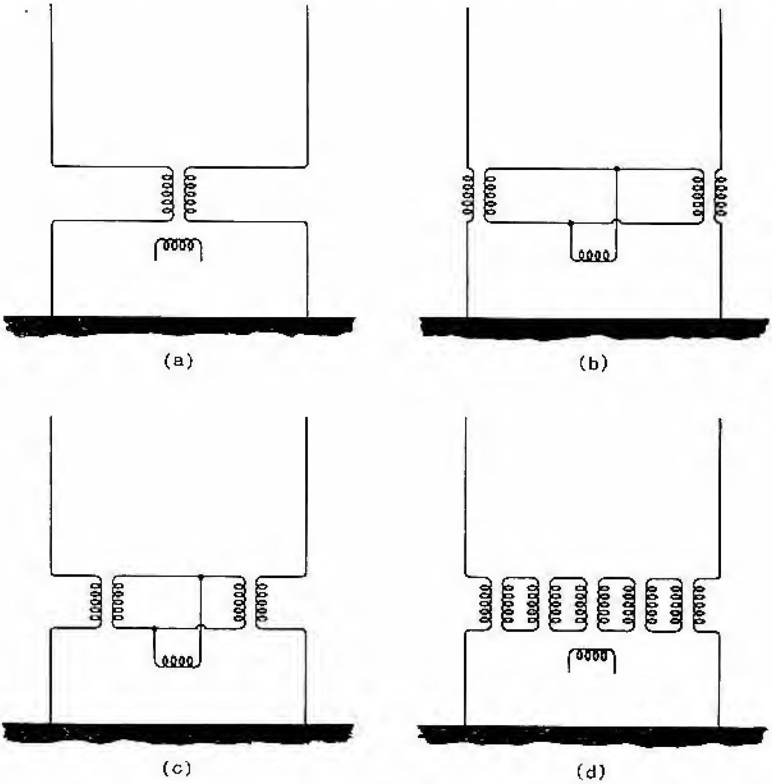


Fig. 218.—Forms of Coupled Aerials.

analagous to the use of loosely coupled circuits for reducing antenna effect in a closed loop D.F. circuit.

Some arrangements of the circuit are shown in Fig. 218,

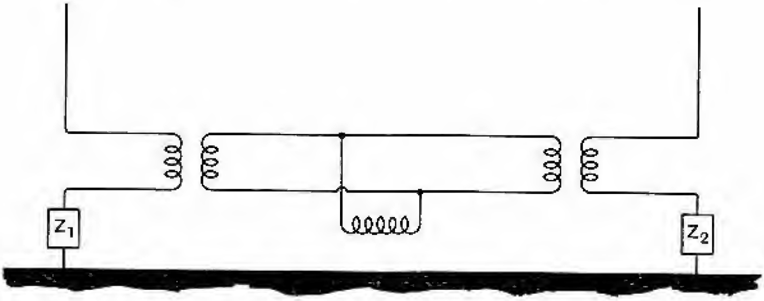


Fig. 219.—The Balanced-Coupled Aerial.

though in practice the horizontal members and the transformers are screened. The standard wave error both calculated and as a result of observations, was found to be only 2° (3015, 3504).

THE BALANCED-COUPLED TYPE

The last two types may be combined as in Fig. 219 with a marked reduction of standard wave error to about 1° on 300 metres. The results of a series of tests using this aerial are given below.

COMPARISON OF BALANCED-COUPLED AND BURIED " U " AERIALS

The investigations by R. H. Barfield (Radio Research Board) concerning the various types of Adcock aerial have already been mentioned. This work was throughout in the nature of pure research, in that a solution of the problem of polarization errors was being sought without any regard to the commercial value of the method finally adopted and hence the great promise shown by the Balanced-Coupled aerial had been followed up.

The Marconi Company, on the other hand, had, during a number of years been striving after a system that, whilst giving reasonable freedom from errors, would at the same time be essentially commercial in respect of such matters as flexibility over a wide range of wave lengths with minimum aerial adjustments, and capable of being shipped to distant parts of the world for local erection and operation. The Buried " U " type offered these advantages.

In March, 1935, a series of experiments was carried out at the Radio Research Station of the National Physical Laboratory at Slough for the purpose of the comparison of the two systems. Some 3,500 observations were made with the balanced-coupled system on the same transmitting station that had been used by the Marconi Company in the Buried " U " tests shortly before, namely, Kalundborg (page 239). The results of these observations are described by R. A. Watson-Watt (3615).

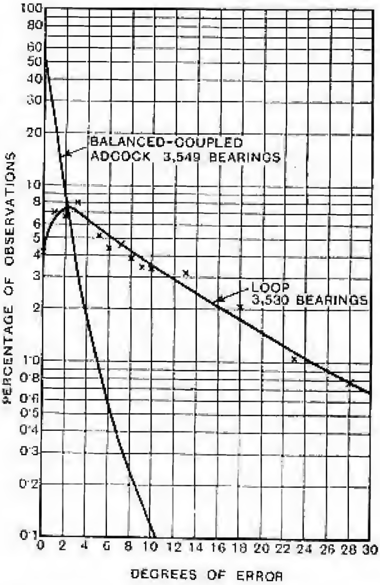


Fig. 220.—Summary of Radio Research Board Tests on Balanced-Coupled Aerial (*Wireless Engineer*).

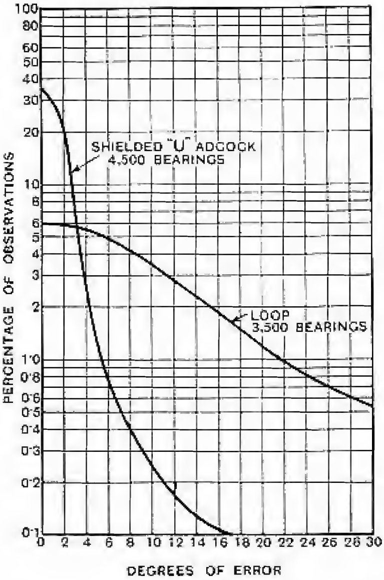


Fig. 221.—Summary of Marconi Company Tests on Buried "U" Aerial (*Wireless Engineer*).

Fig. 220 shows the results of the above tests for comparison with those obtained with the Buried " U " (called Shielded " U ") aerial in Fig. 221 and the improvement is at once noticeable. Unfortunately, since the tests were not carried out simultaneously, the loop D.F. Standard Deviations (page 555), are different, namely 12·35° for the Chelmsford test and 8·36° for Slough, and hence it becomes unfair to make a direct comparison of the two Adcock aerials. It is not unreasonable however (3615), to apply a correction to the Adcock results making the Standard Deviation for the Slough results greater in the proportion of 12·35 : 8·36, which gives a comparison as follows :—

	Loop	Buried “ U ”	Balanced-Coupled	
			Before Correction	After Correction
Standard Deviation ..	12·35°	2·37°	1·05°	1·54°
Standard Wave Error (from experimental results)	—	7°	—	4°
Standard Wave Error (from Barfield's formula)	35°	6°	—	1°

These figures show that whilst a marked reduction in error is achieved with the balanced-coupled aerial, there remains a big discrepancy between the experimental and the theoretically possible results. After examining the possible causes of this, the conclusion was reached that the conditions were probably being approached when Lateral Deviation begins to play a larger part than the properties of the aerial in the all-night-time accuracy of the system.

Subsequent work with an improved system, however, gave results that seemed to point to the previous residual errors being due to incorrect balancing.

THE TRANSMISSION LINE (T.L.) TYPE

This arrangement is somewhat like the Buried “ U ” type in that buried feeders are used to connect the spaced aerials, but there is the essential difference that the opposite spaced aerials are not carried down coaxial feeders to a physical connection through a radiogoniometer field coil. Instead of this, each aerial is earthed at its base and is coupled by a matching transformer to a twin-wire feeder leading to the radiogoniometer as shown in Fig. 222. Across the aerial winding of the transformer is a balancing network consisting of a variable condenser and resistance, which is used to obtain equality of output from the two aerials both regarding amplitude and phase. This enables allowance to be made for unequal effective height of the aerials and for unequal feeder attenuation, and so avoids the production of an appreciable quadrature component such as may exist in the vector sum of the e.m.f.'s of the buried “ U ” aerial (page 236).

For sense determination and for the removal of any residual quadrature e.m.f., a separate open aerial is used at the centre of the four spaced aerials and it employs a fifth transmission line.

This system is commonly used with lines of about 100 yards

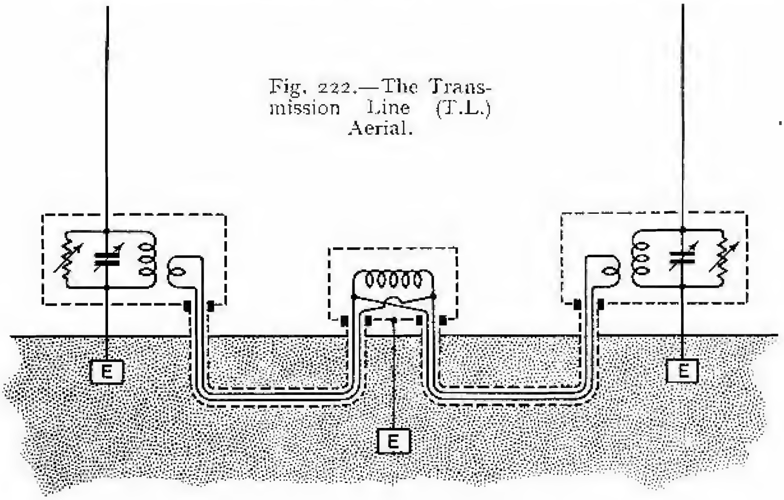


Fig. 222.—The Transmission Line (T.L.) Aerial.

in length, which may be extended to 600 yards with slight loss of signal strength and further details of this arrangement are given on pages 315 and 342.

The " T.L." type aerial is also used for transmission and has been developed by the U.S. Bureau of Standards for use with equi-signal transmitting beacons (page 482.)

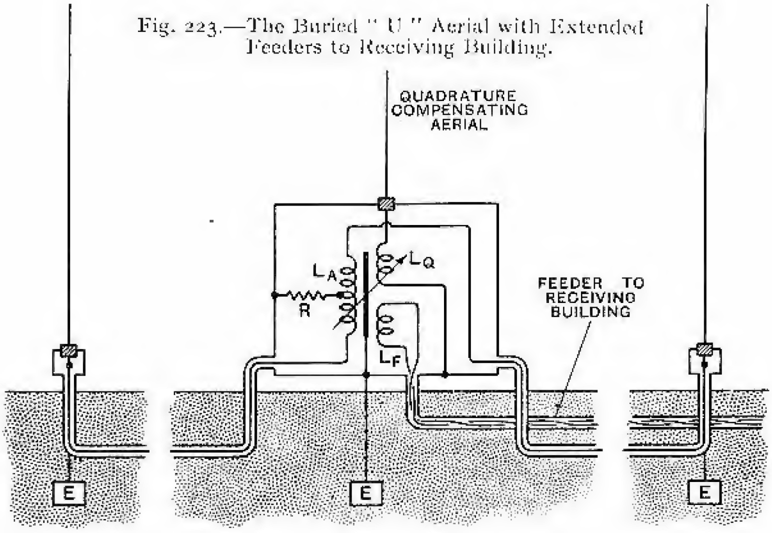
ADCOCK AERIALS USED WITH LONG TRANSMISSION LINES OR FEEDERS

The use of long transmission lines with the B-T aerial has been mentioned in Chapter 5 and the following section deals with their application to the Adcock aerial to enable a centralized D.F. control, as well as W/T and R/T transmission and receiving control, to be employed at the Administrative buildings of an airport. Two types of Adcock aerial are in use with long lines, namely the Buried " U " and the Transmission Line or " T.L." type which has just been mentioned in this connection.

The Buried " U " Aerial with Extended Feeders. The principle of the buried " U " aerial has been described on page 235 and the chief modifications required, when extended feeders are used, are shown in Fig. 223. In this diagram, two diagonally opposite aerials are led, as before, to the centre of the system by concentric buried feeders, but are now connected to the winding L_A of a matching transformer, the centre of which winding has an earth connection through the leak resistance R. A secondary winding L_F is attached to the twin-wire transmission line and thence to the radiogoniometer at a distance of anything up to about 1 kilometre. The transformer has an earth-connected capacity screen.

The elimination of quadrature e.m.f. with extended feeders is less straightforward than with a radiogoniometer on the aerial site. If a fifth aerial be erected and the output conveyed by feeder to a distant radiogoniometer and receiver input circuit, it is found impracticable to correct for quadrature e.m.f. that exceeds 5% to 10% of the cosine maximum, without causing distortion of the bearings. The bulk of the quadrature effect is accordingly removed locally. Near the centre of the spaced aerials is erected a small quadrature compensating aerial, connected through a tertiary winding L_Q of the spaced aerial transformer to earth. The small dimensions of this aerial ensure a leading current so that the e.m.f. induced by it in L_A will be in phase or anti-phase with the wave and hence with the quadrature e.m.f., if any, in the spaced aerial circuit (page 237). The e.m.f. is then adjusted

Fig. 223.—The Buried "U" Aerial with Extended Feeders to Receiving Building.



by methods mentioned again on page 315 until the quadrature effect is reduced to a small enough figure to allow the residue to be removed at the receiving point. A second quadrature compensating aerial is rigged for the second pair of diagonally opposite spaced aerials.

Even if it were convenient to make full correction at the receiver, there is some advantage in the case of the buried "U" type aerial in doing it in the above way since both minima of the cosine diagram will be equally sharp instead of one being sharpened at the expense of the other (page 91).

PROBLEMS IN THE COMMERCIAL APPLICATION OF THE ADCOCK SYSTEM

The commercial installations of the Adcock aerial are described in greater detail in Chapter 9 (Medium wave) and Chapter 10 (Short wave), together with some notes on its adjustment under working conditions. An outline is given below of some of the ways in which Adcock working differs from closed loop practice, and also the principles involved in the aerial feeder connections and receiver input circuits, particularly with regard to the long- and medium-wave layout.

Necessity for a Sensitive Receiver. Apart from direction finding, communication by both R/T and W/T has to be carried out between aircraft and the ground D.F. station and it is very desirable that when an Adcock aerial is in use for D.F., it should also be available for communication purposes.

In comparing the Adcock aerial with the spaced loops as a means of reception of vertical polarization only (page 222), it was pointed out that any aerial composed entirely of vertical active members had an inherent disadvantage in its inability to deal with high angle rays. On page 217 it has been noted that the pick-up of a vertical aerial for a down-coming ray is proportional to cos θ where θ is the angle with the ground. Similarly the differential e.m.f. of the two spaced aerials of Fig. 224, which produces the effective received signal in an Adcock system, instead of being proportional to the spacing d of the vertical limbs, is proportional to d' in the path of the wave, which is again equal to d cos θ. Hence

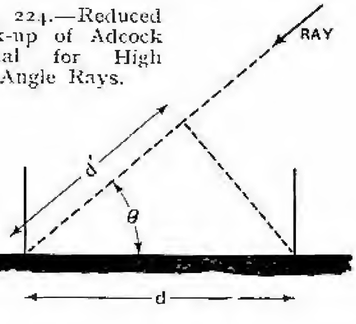


Fig. 224.—Reduced Pick-up of Adcock Aerial for High Angle Rays.

the signal e.m.f. varies as $\cos^2 \theta$ and falls off rapidly for steep angles of elevation, being zero for a vertical ray.

Now the whole success of the aerial depends on rendering the pick-up of the horizontal limbs negligibly small compared to that of the vertical portions. More strictly, it consists in rendering the reception of horizontal polarization negligible compared to that of normal vertically polarized electric force and whilst this may be done for low angle rays, it becomes increasingly difficult as the path of the wave becomes more and more vertical, since the effective wanted pick-up is approaching zero whilst the unwanted pick-up remains constant.

From what has been said in Chapter 6, it will further be realised that, so far as communication is concerned, fading must be exaggerated by the use of an aerial containing only vertical members. If horizontal limbs were also used, the reduction to zero of the vertical polarization at the aerial site, in the trough of a deep fade in this component, would not result in a signal zero unless the horizontal polarization happened to be zero at the same time.

Tests by the Marconi Company (3618) have shown that in comparing a closed loop B-T against an Adcock buried "U", the signals from which in the day time were in the voltage ratio of 2 : 1, there were periods of several minutes duration at night when the ratio was 50 : 1 and even short periods of over 300 : 1 (or 50 db.). During direction finding, the moment may be chosen to avoid an abnormally deep fade, but in communication work, contact must be continuous. On the other hand, direction finding involves operating around the minimum of a cosine diagram which demands a reasonably high signal level.

It is clear that at these very low field strengths a quiet amplifier, giving the maximum possible discrimination between circuit noises and the very minute signals, is an essential. Much work has been done of late regarding this aspect of receiver design and its importance must be recognized in its relation to D.F. work, or it will be poor signal to noise ratio that will eventually limit the range of the D.F. station.

Trailing Aerial Radiation. There is another factor that has a marked effect on Adcock aerial performance and that is the combination of "aeroplane effect" (page 192) and reduced effective height due to the position in space of the trailing aerial, when an aeroplane is moving at high speed.

S. B. Smith and G. H. Hatch (Marconi Company) (3618) give the curve shown in Fig. 225 for the field strength to be expected at varying distances from an aeroplane with 200 feet trailing aerial, flying at 100 to 140 miles per hour over soil of 10^{-13} c.g.s.

units conductivity and with a transmitting power of 100 to 160 watts. At this speed, the effective height of the trailing aerial is reduced to 6 or 7 m. and the field strength, which at 30 km. range is 40 db. up on 1 μV/m. (i.e. 100 μV/m.), is reduced to 10 db. up, or 3 μV/m. at 300 km., and to something like $1\frac{1}{2}$ μV/m. at 400 km., which is not an abnormal range.

H. Fassbender (3319) says that tests by the Radio Division of the German Aircraft Research Establishment have shown that, at 220 miles an hour, the standard trailing aerial has still about twice the effective height of the best fixed aerial that can safely be rigged. The solution therefore does not seem to lie in this direction, and it is a disturbing thought that with the increasing speed of modern aircraft, not only will the effective height of the transmitting aerial become steadily less, but the proportion of horizontal to vertical polarization will increase, and this increased "aeroplane effect" will tend to produce greater polarization errors.

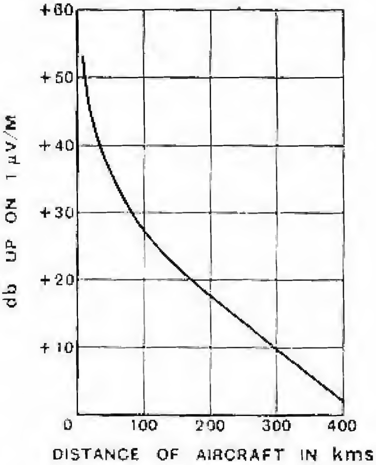


Fig. 225.—Field Strength from Typical Aircraft Transmitter (*Marconi Review*).

Octantal Error due to Aerial Spacing. When discussing the General Case of Two Spaced Open Aerials in Chapter 3 and in particular the central summation of the effects of two such aerials in opposition, which constitutes the simple frame, or, more accurately, the screened "U" type Adcock, it was seen that the system only follows the cosine law for varying angles of horizontal incidence so long as the spacing of the aerials is small compared to the wave length. A well designed radiogoniometer, on the other hand, has a true cosine law coupling between its search coil and each field coil, so that if used in conjunction with an aerial system having some other law, errors will result at various points on the scale. Fig. 226 shows a set of curves for a short-wave Adcock aerial system of 20 feet (6.1 m.) spacing, for wave lengths between 14 m. (21,400 kc.) and 28 m. (10,700 kc.). The error is seen to be positive in the first half quadrant from 0° to 45°, and then alternately negative and positive in succeeding half quadrants. It may be noted that this error varies widely with wave length, and there is no alternative but to make the radiogoniometer with as correct a law as possible and to allow a correction for the aerial spacing error.

If possible, the spacing should not exceed about one tenth of the shortest wave length to be used, in which case the error is negligible. When the spacing has been increased to one-fifth of a wave length, the maximum octantal error is one degree. From the curves of Fig. 58 it will be seen that for spacings of $\lambda/16$ and $\lambda/8$, the polar curve is almost indistinguishable from the cosine diagram, though for $\lambda/4$ the circles are beginning to be noticeably flattened.

The abscissæ of Fig. 226 are the angles between the search coil and field coil of the radiogoniometer and will only coincide with scale readings when the aerials are laid out N. S., E. and W. If the aerials are at, say, 30°, 120°, 210° and 300,° the pointer will have been rotated clockwise through 30° from the axis of the search coil and 30° must be added to the abscissæ to convert them to scale readings. Zero error will then occur at 30°, 75°, 120°, 165°, etc.

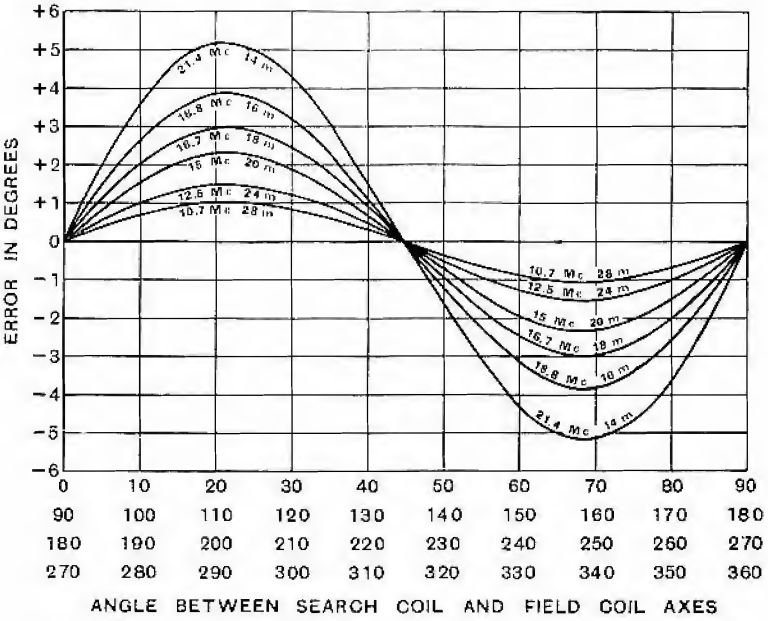


Fig. 226.—Aerial Spacing Error Curves for Short-Wave Adcock Aerial having 6·1 m. Spacing of Vertical Members (Marconi).

Calculation of the Error. The error due to aerial spacing can be calculated in the following way. In Fig. 227 let N.S. be the North-South aerials of the system and let θ be the true bearing of the incident signal. Then, if α be the observed bearing from the scale of the radiogoniometer, it can be shown that :—

$$\tan \alpha = \frac{\sin (\phi \sin \theta)}{\sin (\phi \cos \theta)}$$

where $\phi = \frac{\pi d}{\lambda}$, d being the aerial spacing.

Once again, if ϕ is small, $\tan \alpha = \tan \theta$, so that the law of the radiogoniometer is satisfied (page 140).

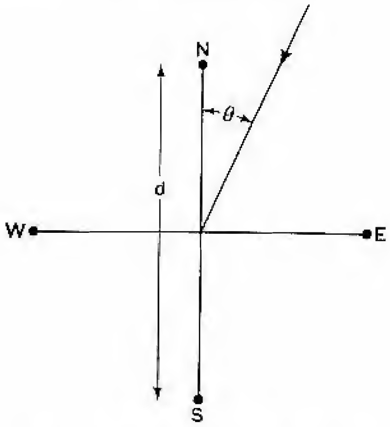


Fig. 227.—Aerial Coupling Error.

Nomenclature. In this chapter, in order to distinguish between the arrangements of Fig. 203 and 206, they have been termed the " shielded " and the " buried " types of " U " aerial respectively. In practice, the forms shown in Fig. 203, 204 and 205 are rarely, if ever, used and the name " shielded U " is generally taken to imply that the aerial is also buried. The terms " shielded " and " buried " may be considered as synonymous in later chapters.

CHAPTER 8

MAPS

In order to appreciate to the fullest extent the ways in which the wireless direction finder may be used as an aid to navigation in the case of a ship or aircraft, or as a simple direction or position finder in the case of a shore station, it is an advantage to have a thorough acquaintance with the various types of maps which are used for the work. Furthermore, in the former case, in which the direction finder is installed on board a moving object, a knowledge of the elements of navigation is advisable, in order to make intelligent use of the apparatus.

This chapter deals with some of the ways in which the surface of the earth may be represented as a map or chart, showing their uses and limitations, as applied to wireless direction finding.

The Earth. The shape of the earth is that of a slightly flattened sphere, with the maximum diameter of 7,926 statute miles at the Equator. The Poles are at the extremities of the minimum diameter of 7,900 statute miles and this is also the axis about which the earth rotates from West to East.

Angular Latitude and Longitude. When considering the subject of maps, it is useful to keep always in mind the fact that latitude and longitude represent not merely a system of lines symmetrically spaced on the earth's surface, but rather that they are essentially angular. Whilst the importance of this point may not be so apparent when using latitude and longitude simply to give a name to a certain point of the surface of the earth, a clear understanding of the first principles of the subject will be found essential in practical map projection, in the calculation of azimuths from astronomical observations, or even in working out Great Circle angles and distances. All the above subjects may enter into practical wireless direction finding and are dealt with either in this or subsequent chapters. Fig. 228 and Fig. 229 show the relation between what are termed "Angular" and "Linear" Latitude and Longitude.

Linear Latitude and the Nautical Mile. The nautical mile at any place is the length of an arc of the meridian, in the vicinity of that place, which subtends an angle of 1 minute at the centre of curvature. Owing to the fact that the earth is not a true sphere, this distance varies slightly at different

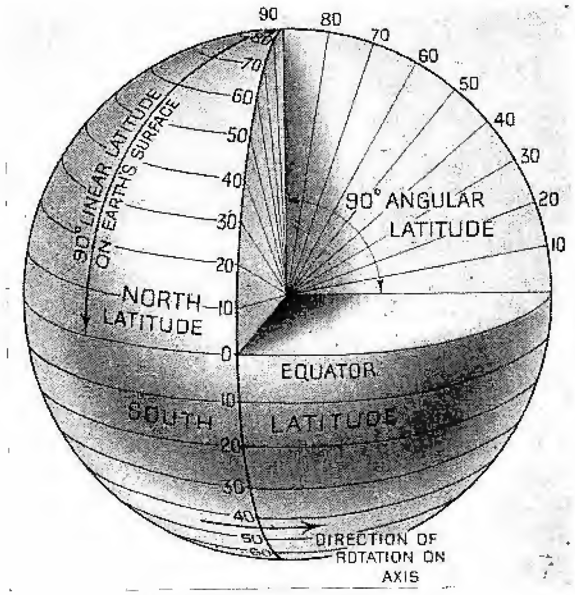


Fig. 228.—Latitude.

latitudes, being equal to 6,107·9 feet at the poles and 6,045·7 feet at the equator. Assuming the earth to be a perfect sphere, the length of an arc of meridian subtending 1 minute at the centre is 6,077 feet, and the nearest round number has been taken as the **Mean Nautical Mile,** namely, 6,080 feet, or 1·152 times the **Statute Mile** of 5,280 feet.

Linear Longitude and the Geographical Mile. Whilst the length of 1 minute of arc of meridian is seen to vary only very slightly in different latitudes, the length of 1 minute of arc of latitude (*i.e.*, 1 minute of longitude) varies from nothing at the poles, where the meridians converge, to a maximum at the equator equal to 6,087·1 feet, and this latter distance is known as a **Geographical Mile.**

Great Circles. The Great Circle is the name given to any circle on the earth's surface, the centre of which is at the centre of the earth. Another, and perhaps more strictly accurate definition, is that the Great Circle is the intersection of the earth's surface with a plane which contains the earth's centre. It will be seen that there may be an infinite number of Great Circles, and that they have the maximum possible diameter, which is the diameter of the earth itself. The equator is a Great Circle, since the equatorial plane contains the centre of the earth, although the remaining parallels are not Great Circles. All the meridians are semi-Great Circles but they are, however, special cases since they all pass through the poles.

Fig. 230 shows a photograph of a globe with three Great Circles passing through London, and an important point to notice is that any Great Circle, except the equator, cuts successive meridians at different angles. For instance, the one which passes through Vancouver leaves London in roughly a north-westerly direction ; just to the west of Greenland it is travelling due West and is again making an acute angle with the meridian at Vancouver.

The difference between the angles of intersection with any two meridians is known as the **Convergency,** and is an important factor in wireless direction finding work.

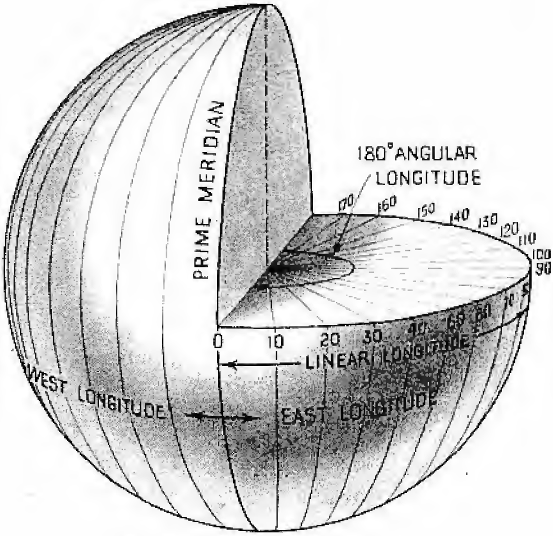


Fig. 229.—Longitude.

Great Circle Distance. Just as in the case of the plane surface, where the shortest distance between two points is the straight line joining them, so on the surface of a sphere the shortest distance between two points, measured along the surface, is the arc of the Great Circle which passes through them and is known as the Great Circle Distance. (See page 745 for method of calculating Great Circle Distance.)

Long and Short Great Circle Track. Electromagnetic waves always travel radially outwards from the transmitting station and hence any given portion of the wave front normally follows a Great Circle path from transmitter to receiving station. It does not follow a curved path except in as much as the earth's surface is curved. Now since a Great Circle passes completely round the earth it follows that there are always two paths, starting out in diametrically opposite directions, from any one point on the earth to any other point. It is very important to realise—and not perhaps very obvious

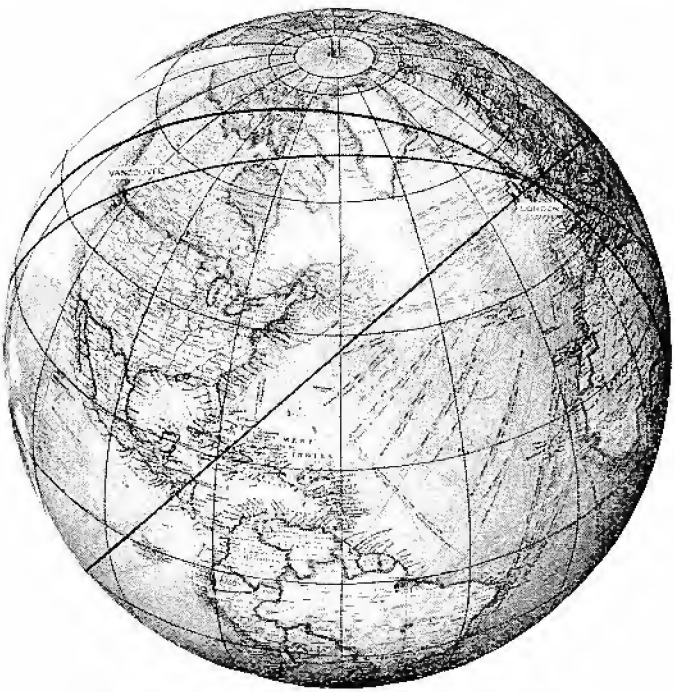


Fig. 230.—Great Circles. Illustrating Convergency.

at first sight—that these two paths, the long and the short Great Circle path, are the *only possible tracks which a wave can normally follow between transmitting station and receiver.* As an instance of an abnormal path may be mentioned " lateral deviation " (page 229), but in general the section of the wave front which leaves the transmitter in any other direction, simply passes round the earth along some other Great Circle and does not reach the receiver. Of course in the special case when the receiving station is at the **Antipodes** of the transmitter, that is to say, at exactly the opposite side of the earth, then all Great Circles from the one will pass through the other.

Maps. Since the exact reproduction of the curved surface of the earth to a large scale is not practical, it is usual to attempt to represent it in the form of a map or chart on a plane surface, but owing to the impossibility of reproducing accurately a curved surface on a plane, a certain amount of distortion is bound to take place.

There are about thirty different types of maps in use for atlases, surveys, charts, etc., but many more than this have been prepared for the sake of special properties or combinations of properties not possessed by any one of the others. There is no special object in detailing the names of all these different methods of map projection, and space certainly does not permit of a description of them, so we will pass on to the process of wireless direction finding and the conditions a map must satisfy in order to be of use for this work.

The basic principle of wireless direction finding consists in the measurement, at a receiving station, of the angle between the direction of true North (*i.e.*, the meridian through the place) and the direction of travel of the electromagnetic waves which are arriving from a distant transmitting station. This angle is known as the **True Bearing** of the distant station, at the place, and is illustrated in Fig. 231. In some cases, particularly in the navigation of ships or aircraft by means of a direction finder installed in the vessel, it may be required to measure the angle between the directions of travel of waves from two distant transmitting stations, irrespective of their true bearings. In either case the angle measured is that made by the intersection of Great Circles, and it is therefore necessary that the map on which the operation is reproduced must be of such a character that *Great Circles appear as straight lines.* Only when this is the case can the paths of electromagnetic waves from transmitting to receiving station be quickly and accurately drawn and the angles measured by means of an ordinary protractor.

THE GNOMONIC PROJECTION

A map projection on which all Great Circles are represented as straight lines is known as **orthodromic** and if, in addition, the angles subtended at a certain point by all other points on the projection are correctly rendered, it is sometimes termed **azimuthal** but more generally **zenithal.***

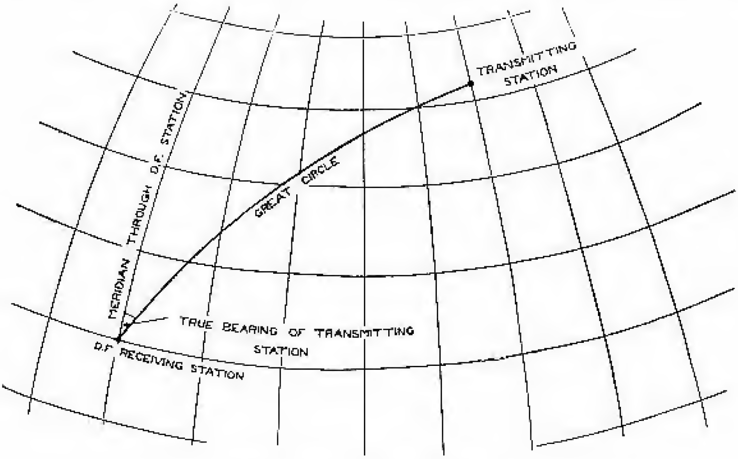

TRANSMITTING STATION
GREAT CIRCLE
MERIDIAN THROUGH D.F. STATION
TRUE BEARING OF TRANSMITTING STATION
D.F. RECEIVING STATION

Fig. 231.—True Bearing.

This confusion is unfortunate since the two words have quite distinct meanings in astronomical work and azimuthal is associated with horizontal angles (page 714). The name zenithal was, however, used in the above connection by Germain—a French writer of a classic work on map projections—and the term has been retained, somewhat under protest, by subsequent authors.

A projection that has these properties and which has an extensive use in D.F. work is the **gnomonic** projection, which belongs to a family known as **perspective** projections, so called because their shape is the same as that which would be presented if it were possible to view the area concerned from the centre of the earth.

A clear conception of the properties of the projection may be had by supposing it to be obtained by optical means.

Fig. 232 shows a transparent model globe of the earth, which has a light at the centre. On this globe are marked the lines of latitude and longitude, and if a tangent plane be applied at, say, the point O, then the shadows of all Great Circles, whether they pass through O or not, will appear as straight lines since the source of light is in the plane of each of the Great Circles and cannot, therefore, throw a curved shadow. This means that all the meridians of longitude will be straight lines, and if any random Great Circle be drawn through O, this will be projected on the tangent plane as a straight line OP and, what is more important, the angle between the Great Circle and the meridian through O is correctly reproduced in the shadow map.

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* Azimuthal was used in the first and second editions of this book.

The point O is known as the **Point of Contact** since it is the point where the surface of the globe and the tangent plane touch. This is the only point at which the angles of intersection of Great Circles are correctly rendered, although the errors at other points up to 5° or so distant from the point of contact are negligible for commercial D.F. work.

If a gnomonic chart be used for an area having several widely separated D.F. stations, the alternative is to have a special protractor drawn round each station, the scale of which is modified so that bearings are correctly rendered with reference to the graticule (see Fig. 467).

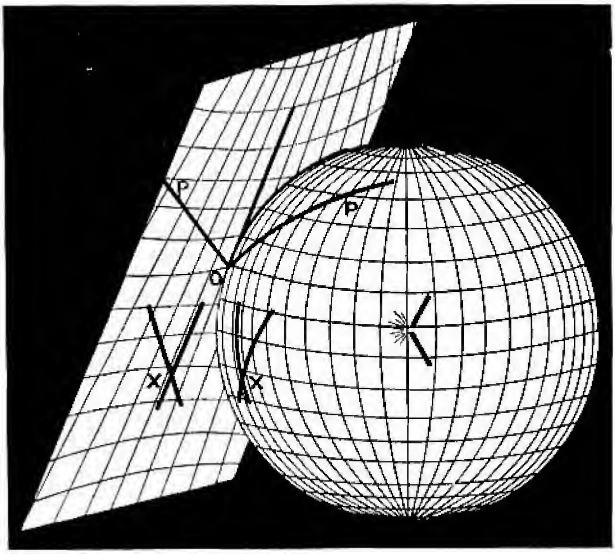

Fig. 232.—Gnomonic Projection of Globe by Optical Means.

Fig. 233 shows the relative disposition of the tangent plane for a gnomonic chart extending over 25° of latitude and the portion of the globe which it represents. It can easily be shown that the distance LM is slightly greater than the corresponding distance *lm* on the globe, and that this discrepancy increases rapidly as the distance from the point of contact P increases. For this reason, Great Circle distances between points on the chart cannot be scaled off accurately, except near the point of contact. A zenithal chart can be constructed on which distances can be scaled off accurately from the point of contact, and is known as a **zenithal equi-distant** projection (2209).

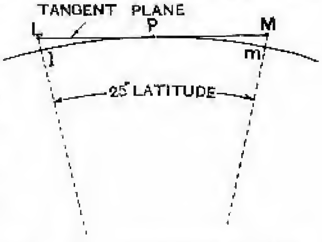

Fig. 233.—Distances on the Gnomonic Projection.

It may be interesting at this point to study the various forms which the charts will take when the point of contact is taken at different positions on the earth's surface. Suppose, for instance, the point of contact to be taken at the pole. The meridians will then be straight lines, radiating from the point of contact, since they are actually Great Circles passing through the pole, and the parallels of latitude will appear as concentric circles about the pole. Again, if the point of contact be taken, say, in latitude 40° N., the chart will appear as in Fig. 467, and so on, the meridians becoming more and more nearly parallel straight lines as the point of contact gets further from the pole, until, when it reaches the equator, the meridians are parallel straight lines and the parallels are very flat curves, convex to the equator which is a straight line through the point of contact.

It will be seen that the meridian on which the point of contact is taken does not effect the appearance of the chart at all; only the latitude of the point can do this. The result is that the chart which in Fig. 445 is seen to extend from 47° 30′ to 62° 30′ north latitude, may be used for any part of the globe within this zone of latitude in the northern hemisphere, and if turned upside down could be used for the corresponding zone in the southern hemisphere. It is, therefore, a fairly simple matter to have a set of gnomonic charts available for any part of the globe.

The Gnomonic Graticule. In preparing a series of charts, each of which is suitable for a given belt of latitude, it will be an advantage to have no coast lines or physical features whatever marked on the chart, and only the lines of latitude and longitude. Such a network of parallels and meridians is known as a **Graticule,** as distinct from a map or chart. (The more popular, if less strictly accurate name of " chart " will be used throughout the book, except where it might lead to confusion.) As mentioned above, the gnomonic graticule is a function of the latitude only, and may be used in any longitude, and it is therefore usual to print only the values of the latitude and to leave the meridians blank, so that they may be given values later, depending on the part of the world in which the chart is to be used.

Twenty-five Miles to the Inch Gnomonic Charts (Graticules). Such a series of gnomonic charts was prepared by the Marconi Company some years ago, chiefly for use when calibrating shore D.F. stations, but also for use in ships when taking long distance wireless cross-bearings, examples of which are given in Chapter 14. (The method of construction of a gnomonic graticule is described on page 749.) There were twelve of these charts, and Fig. 234 shows the twelve tangent planes in their position on a globe, from which it will be seen that a chart is allotted to every 10° of latitude, the number of degrees of longitude depending on the latitude. The point of contact is taken at the centre of the tangent plane, but is not shown in the finished chart. The overlap of the charts, which is not shown in the figure, is 2° 30′ of latitude, both north and south, so that the total range of latitude is 15°.

Particulars of the complete series are as follows :

	Limits of Latitude.	
Name.	North.	South.
F	62° 30′ N.	47° 30′ N.
G	52° 30′ N.	37° 30′ N.
H	42° 30′ N.	27° 30′ N.
J	32° 30′ N.	17° 30′ N.
K	22° 30′ N.	7° 30′ N.
L	12° 30′ N.	2° 30′ S.
L (Reversed)	2° 30′ N.	12° 30′ S.
K	7° 30′ S.	22° 30′ S.
J	17° 30′ S.	32° 30′ S.
H	27° 30′ S.	42° 30′ S.
G	37° 30′ S.	52° 30′ S.
F	47° 30′ S.	62° 30′ S.

Note that the charts for the southern hemisphere are obtained by reversing the corresponding charts of the northern hemisphere, the numbering of the latitude being arranged so that the figures in the *left hand margin* always read the correct way up for the chart (see Fig. 445). The method of using the gnomonic graticule is described on page 579.

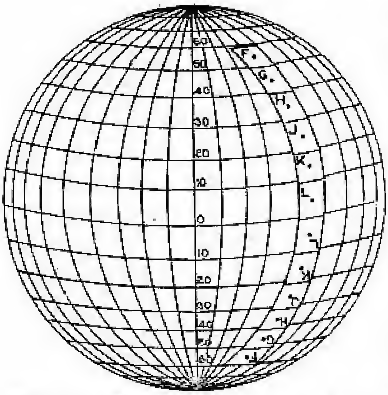

Fig. 234.—Tangent Planes of a Series of Gnomonic Projections.

The Retro - Zenithal Chart.* There is another one of the family of map projections to which the name gnomonic or zenithal projections belongs, which is worthy of note, though it is not proposed to deal with it at any great length. We saw that the gnomonic projection had the property of rendering all Great Circles as straight lines, and the correct true bearings of all points on the chart *from a certain point* which was called the "point of contact." It is possible to produce such a projection that the true bearings of either one or two certain points on the chart *from all other points* are rendered correctly, but the chart is not orthodromic. The names given to this type of chart are **Retro-Zenithal** and **Bi-Retro-Zenithal** respectively, depending on whether the chart is retro-zenithal with respect to one or two points. The projection has possibilities in connection with navigation over long distances between wireless transmitting stations used as terminal beacons.

THE MERCATOR'S PROJECTION

In the foregoing remarks on the selection of a chart for direction finding, no allusion has been made to the Mercator's chart, which is probably one of the most familiar methods of representing the earth (with the exception of the polar regions), on a single sheet, and which is almost universally used for nautical charts.

This map is one of a class called **Cylindrical Projections** and it is possible to obtain a fairly clear conception of some of its properties by considering the method in which a type of cylindrical projection may be obtained by the optical method, making use of the transparent globe with a light at the centre.

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* See footnote on page 260.

Reverting to Fig. 232, we saw that if the tangent plane were made to touch the globe on the equator, the meridians were all projected as straight lines and the parallels were curves, convex to the equator. Suppose, now, that the surface on which the projections have been made, and which hitherto has been assumed to be a plane, be bent into the form of a cylinder, making line contact with the surface of the globe, along the equator. An investigation of Fig. 235 and a few moments consideration will indicate that, whilst the meridians are still projected as straight lines, the parallels of latitude are now projected as parallel circles. The distance between successive parallels on the cylinder is seen steadily to increase with the distance from the equator, and it is not possible to reproduce the polar regions, since the pole itself will be at an infinite distance.

If this cylinder be now opened out, we have a chart similar to that shown in Fig. 236, and which suffers from several disadvantages. In the first place, the only part of the map at which the scales of latitude and longitude are the same is along the equator. It is clear that the scale of longitude must increase as we approach the pole, since the meridians are parallel in this map, whilst actually we know they converge towards the pole. In the same way the scale of latitude is rapidly increasing as we move away from the equator, since the poles are at an infinite distance from the equator on the map. These two scales are also increasing at different rates, with the result that at any point on the map a distance of, say, ten miles, measured east and west, and a similar distance measured north and south, are represented on the map by quite different lengths; so that if the projection were used

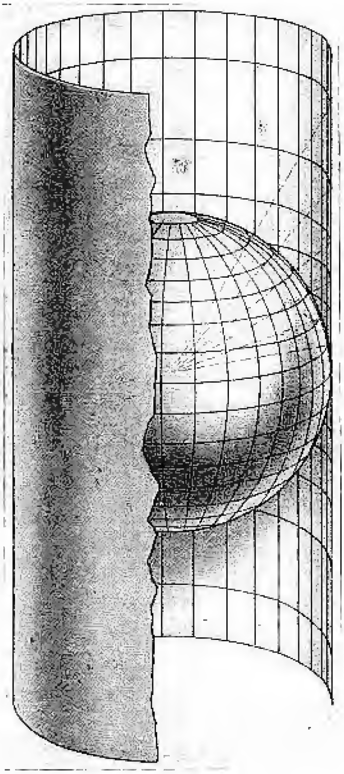


Fig. 235.—Cylindrical Projection of Globe.

for a map of the world, all the countries would be grossly distorted in shape, and even the smallest angle or bearing, as measured on the map, would be incorrect.

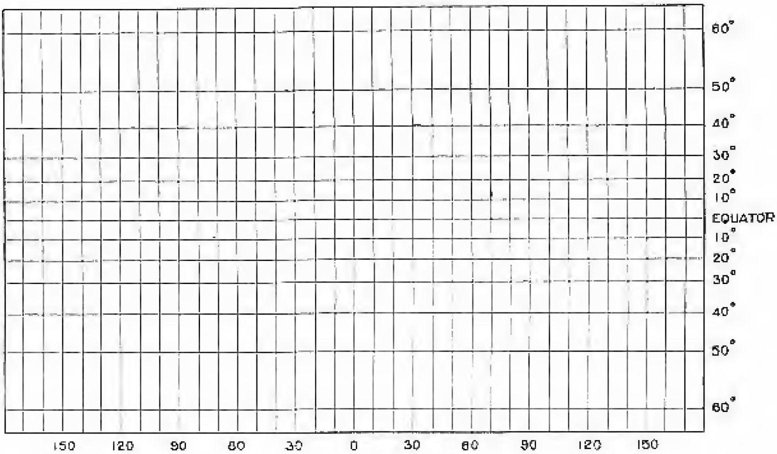


Fig. 236.—Development of Cylindrical Projection of Fig. 235.

The cylindrical projection shown in Fig. 236 is therefore modified in such a manner that at any given point the scale of latitude and longitude is the same (though the scale varies with the latitude), the chart becoming what is known as **Orthomorphic,** or capable of representing small areas in their correct shape, and this is the **Mercator's Projection.**

Distances on a Mercator's Chart. Since the scale of both latitude and longitude varies with the latitude, it is not possible to use any fixed scale in the measurement of distances between places unless they lie on the same parallel. On all nautical charts, however, the latitude is marked in the margin on both sides of the chart, the degrees being sub-divided into minutes of linear latitude which, it will be remembered, correspond to nautical miles. It is thus only necessary to set a pair of dividers to the

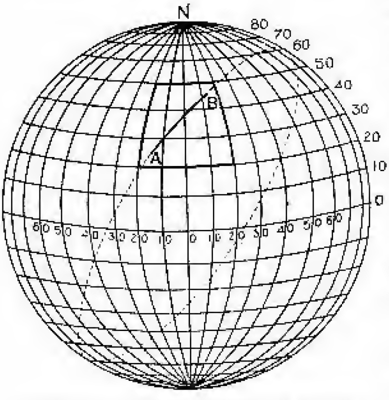


Fig. 237.—Great Circle on Globe.

distance on the chart to be measured, and use as a scale that portion of the marginal latitude scale which most nearly coincides with the latitudes of the points under consideration.

Comparison of Properties of Gnomonic and Mercator's Charts. In Fig. 237 is shown the globe, which is the only "map" which retains all the geometrical properties of the earth itself. A portion of this sphere is lined in from 20° East to 20° West longitude and from 20° to 50° North latitude. Two points on the surface are shown at A and B,

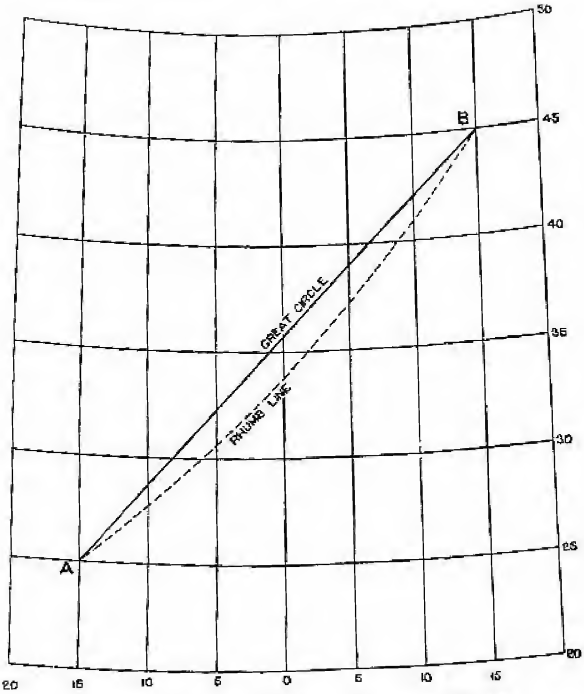


Fig. 238.—Great Circle on Gnomonic Chart.

which have positions respectively 15° W., 25° N. and 15° E., 45° N. Figs. 238 and Fig. 239 show the same portion of the earth's surface on the gnomonic and Mercator's charts, and the following comparison of the three "maps" will illustrate the characteristics of the last two, as compared with the first.

Suppose a Great Circle to be drawn from A to B; on the globe this will appear to be a curve, owing to the perspective of the drawing, though we know that actually it is the shortest distance along the surface from A to B. On the gnomonic chart it is a straight line, and we notice that, as we have already found, it cuts successive meridians at different angles, just as it does on the globe.

There is no simple way of drawing a Great Circle on a Mercator's chart, and the easiest way in this case will be to plot off on the Mercator's chart, the points on the gnomonic chart or the globe, where the Great Circle cuts the meridians. If this be done, the resulting Great Circle will be as shown in Fig. 239, namely, a curved line which is concave to the equator. A method of drawing Great Circles on a Mercator's chart when a gnomonic chart is not available is given on page 748.

The angles at which this line cuts respective meridians will be found to be the same as in the other two figures, but owing to the meridians on the Mercator's chart being parallel, the Great Circle must of necessity appear curved.

Consider, now, what would be the result of using a Mercator's chart for long distance direction finding work. Suppose that in Fig. 239, A represents the position of a D.F. station and B

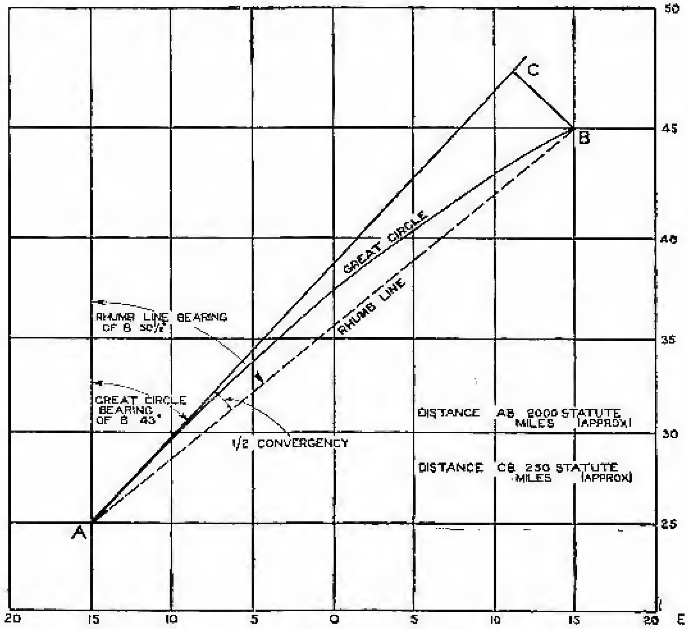

50
45
40
35
30
25
C
B
A
GREAT CIRCLE
RHUMB LINE
RHUMB LINE BEARING OF B 50½°
GREAT CIRCLE BEARING OF B 43°
1/2 CONVERGENCY
DISTANCE AB 2000 STATUTE MILES (APPROX)
DISTANCE CB 230 STATUTE MILES (APPROX)
20
15
10
5
0
5
10
15
20
E

Fig. 239.—Discrepancy between Great Circle Bearing and Mercatorial or Rhumb Line Bearing.

that of a transmitting station about 2,000 miles distant. The path of the wave from B to A will be along the Great Circle, and the apparent direction from which it is arriving at A will be along the tangent to the Great Circle at A, which is the line A C. On the map, the direction of the transmitting station is along the line A B, the error being seven or eight degrees, and the line A C passing B at a distance of about 250 miles.

The angle C A B is equal to one half of the difference between the angles of intersection of the Great Circle with the meridians through A and B, and is called the **Half-Convergency.**

Rhumb Line. Any line which cuts successive meridians at the same angle is called a rhumb line, and since, in the Mercator's chart, the meridians are parallel straight lines, the rhumb lines are also straight lines.

The equator is a rhumb line, since it cuts all meridians at right angles, but it is a special case in that it is also a Great Circle. The rhumb line track is one usually adopted by ships when the voyage is short or when time is not of paramount importance, since it involves less trouble in ascertaining the correct course on which to set the ship. It results, however, in a curved course being taken and such a course or line is called **Loxodromic,** meaning "oblique course," as distinct from orthodromic meaning "straight course." If the Great Circle track be followed, the course will have to be constantly changing, since the bearing of true north varies at every point of a Great Circle, unless it be a meridian or the equator. The dotted line in Fig. 239 shows the rhumb line track, and similarly in Fig. 238, where, owing to the fact that the meridians are not parallel, it appears as a curve, which in fact it is on the surface of the earth, in every case except when the two extremities of the line lie either on the same meridian or on the equator. The angle at A between the meridian of the place and the rhumb line is called the **Rhumb Line Bearing** of B from A.

The World on Mercator's Projection. Fig. 240 shows the world, between the limits of latitude 80° N. and 80° S., on the Mercator's projection and with the same three Great Circles which were drawn in Fig. 230. This illustrates very well the extreme distortion which results from this type of projection. Vancouver here appears to be due West of London although actually it bears nearly North West. Similarly the Great Circle shows that Jamaica is *due West* and Madras *due East* of London and on almost the same bearing from London as Perth in Western Australia. Honolulu is in latitude 30° South of London, but its direction from London is approximately the same as that of Glasgow.

These apparent anomalies can be observed and much other interesting information gained from an inspection of a globe, a small model of which costs only a few shillings.

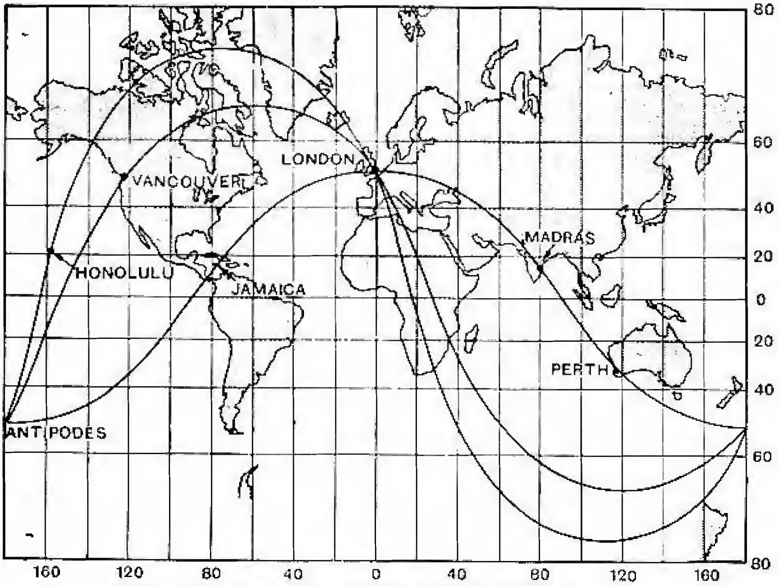


Fig. 240.—The World on Mercator's Projection.

Note that in Fig. 240 the Great Circles all converge on the Antipodes of London, namely Latitude 51° 30′ South and Longitude 180°.

Limitations of the Mercator's Chart for D.F. Work. For distances between receiving and transmitting stations up to 50 or even 100 miles, the rhumb line and Great Circle lie fairly close to one another, and a Mercator's chart may be used for D.F. work with only comparatively small errors. With increasing distance between the stations the discrepancy rapidly increases, and for accurate work a gnomonic chart must be used, unless a correction for half-convergency be applied to the apparent bearings found from the Mercator's chart.

For shore work, gnomonic charts will usually be available for long-range working, but the inconvenience of carrying this type of chart at sea to suit the variety of latitudes in which the vessel may be, during a long voyage, together with the unreliability of night bearings over greater distances, has resulted in a tendency for ship's navigators to rely on short range D.F. bearings of 100 miles or less, in which case they are able to use the standard nautical charts.

▸ **Correction of Convergency Error on Mercator's Chart.** If, for any reason, a long-range station is used, either for calibrating or navigating purposes, when a gnomonic chart is not available, a correction for half-convergency may be applied. In the first case it may be applied to the rhumb line bearing, as read off from the Mercator's chart, in order to convert it to the Great Circle bearing, as observed on the D.F. In the second case of a bearing taken, say, by a ship D.F., of a distant transmitting station, the correction may be applied to the observed bearing in order to find the rhumb line bearing, so that the latter may be laid off on the Mercator's chart and used in order to find the ship's position by methods which will be explained in Chapter 14.

A simple formula exists for calculating the half-convergency and gives results which are accurate to within 10′ of arc at distances between the transmitting and receiving stations of 1,200 miles :

$$\textbf{Half-Convergency} = \frac{1}{2}\left\{\begin{array}{l}\text{Difference of Longitude}\\ \text{between transmitting}\\ \text{and receiving stations.}\end{array}\right\} \times \left\{\begin{array}{l}\text{Sine of the Middle}\\ \text{Latitude between}\\ \text{the stations.}\end{array}\right\}$$

The half-convergency is zero when either of these factors vanish, and this is clearly correct when the difference of longitude between the stations is zero, since when this is the case the stations must both lie on the same meridian, which is,

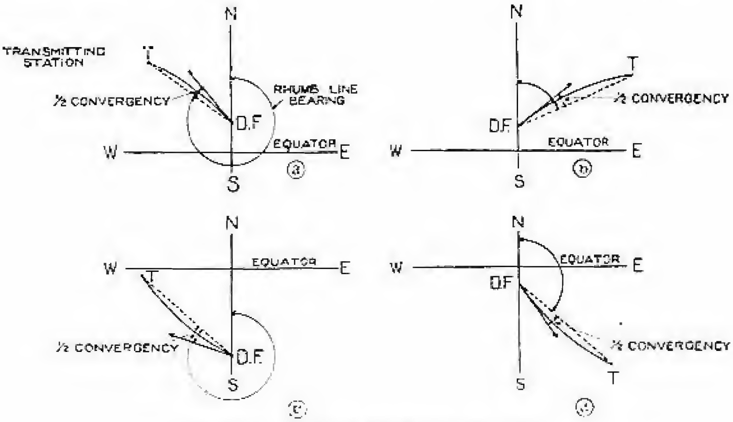


Fig. 241.—Sign of Half-Convergency.

of course, a Great Circle. When the middle latitude is zero (equator), there still remains a slight amount of convergency which, however, may be neglected in all practical cases. The Mercator's chart might be expected to be zenithal in the neighbourhood of the equator, as it will be remembered that in the optical method of producing the cylindrical projection, from which this chart is developed, line contact with the globe occurred along the equator.

Sign of the Half-Convergency. The sign of the correction, that is to say, whether it must be added or subtracted, will depend on the relative positions of the two stations and also on whether it is required to convert rhumb line bearing to Great Circle bearing or vice versa. Bearing in mind that the Great Circle is always concave towards the equator, we can draw a series of diagrams which illustrate how the varying positions of the stations affects the sign of the half-convergency (Fig. 241), and tabulate the results as follows :

	MIDDLE LATITUDE.	TRANSMITTING STATION.	Given the GREAT CIRCLE to convert to RHUMB LINE.	Given the RHUMB LINE to convert to GREAT CIRCLE.
(*a*)	North	West of D.F.	Subtract	Add
(*b*)	North	East	Add	Subtract
(*c*)	South	West	Add	Subtract
(*d*)	South	East	Subtract	Add

NOTE.—All bearings to be expressed in *degrees east of north* before applying the correction.

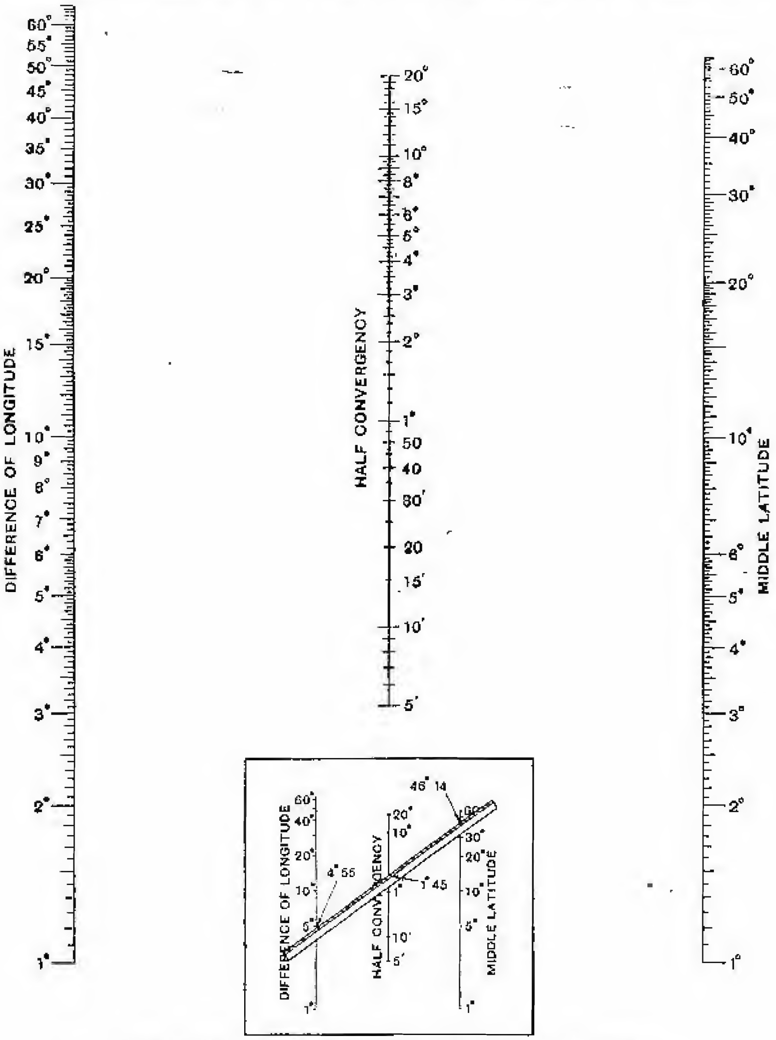
Examples are given in the application of this correction in Chapter 14, both in the case of the calibration of a shore D.F. station and also in aircraft navigation.

Half-Convergency Diagram. In order to obviate the necessity of arithmetic in connection with the use of the above formula when a number of values of half-convergency are required, an alignment chart has been constructed and is reproduced, together with instructions for its use in Fig. 242.

The Line of Bearing. It was seen in Fig. 239 that when using the Mercator's chart for D.F. work over large distances, the apparent direction of a transmitting station B from the D.F. station at A was, in the majority of cases, entirely wrong Referring now to Fig. 243 with the Great Circle through A and

HALF-CONVERGENCY DIAGRAM

TO BE USED WITH MERCATOR'S CHARTS FOR THE CONVERSION OF GREAT CIRCLE BEARINGS TO RHUMB LINE BEARINGS AND VICE VERSA



EXAMPLE OF THE USE OF THE DIAGRAM.

To find the Half-Convergency in respect of two places, the Difference of Longitude of which is 4° 55' and the Mid-Latitude 46° 14', place a piece of stretched cotton or a straight edge, as shown, so as to intersect the outer scales at the given points and read off the Half-Convergency 1° 45', on the centre scale. (For other information see text, pages 272, 582, 606.)

Fig. 242.—Half Convergency Alignment Diagram.

B shown as a full line, and the rhumb line as a broken line, suppose that whilst the rhumb line bearing of B from A is $50\frac{1}{2}°$ East of North, the angle of arrival of the wireless signals along the Great Circle makes it appear to be 43°, *i.e.*, along the tangent A C to the Great Circle.

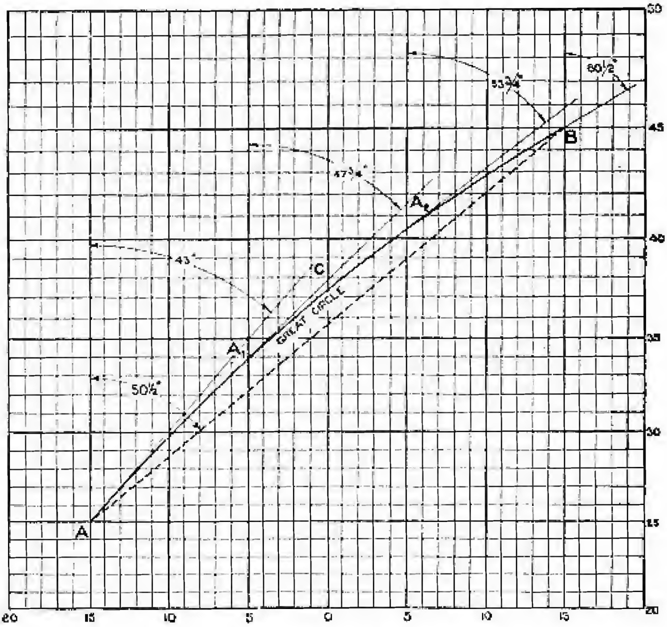


Fig. 243.—Change in True Bearing as A approached B along Great Circle.

If successive points be taken along the Great Circle at A_1, A_2, etc., Fig. 243, indicating the position of the receiving D.F. station as it approaches B along a Great Circle course, the angle which the Great Circle makes with the meridian at the points A_1, A_2, etc., will increase steadily until it reaches B.

Now suppose that Fig. 244 represents the same process, except that A approaches B along the rhumb line. Again we see that the true or Great Circle bearing of B from successive positions of A steadily increases, although to a less extent than before.

There must, however, be some such line that if A approach B along this course, the angle between the tangent to the Great Circle and the meridian at the point will be constant, and Fig. 245 shows the path of such a line. An inspection of this diagram will show that at every point along the line A, A_1, A_2, B, the true bearing of B is constant and equal to 43°, and this line is called a "line of constant bearing," or simply a **line of bearing.**

For short distances between the points A and B, the line of bearing and the Great Circle lie symmetrically on either side of the rhumb line, so that the angle of intersection of these curves is equal to the convergency between A and B.

The lines of bearing of any point, if completed, are found to converge on the pole, the line BA having been drawn in full in Fig. 246.

If lines of bearing were marked on a Mercator's chart for every degree, in connection with a number of long-range wireless transmitting stations, such a chart would at once assume properties, from the point of view of wireless navigation

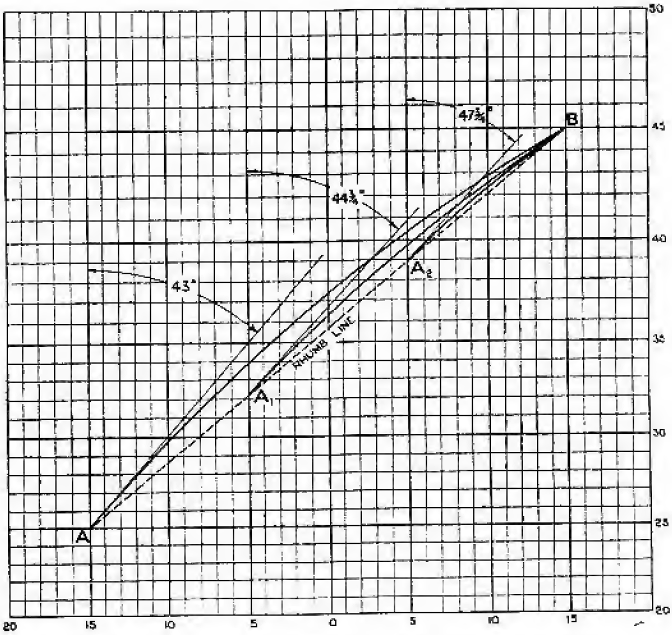


Fig. 244.—Change in True Bearing as A approaches B along Rhumb Line.

by the D.F., which are lacking on the ordinary Mercator's chart, and to which reference is again made on page 585.

It will be seen that this type of map, on which navigation is achieved by making use of lines of bearing on two or more wireless transmitting stations, is very much akin to the retrozenithal type already mentioned. The latter has the advantage

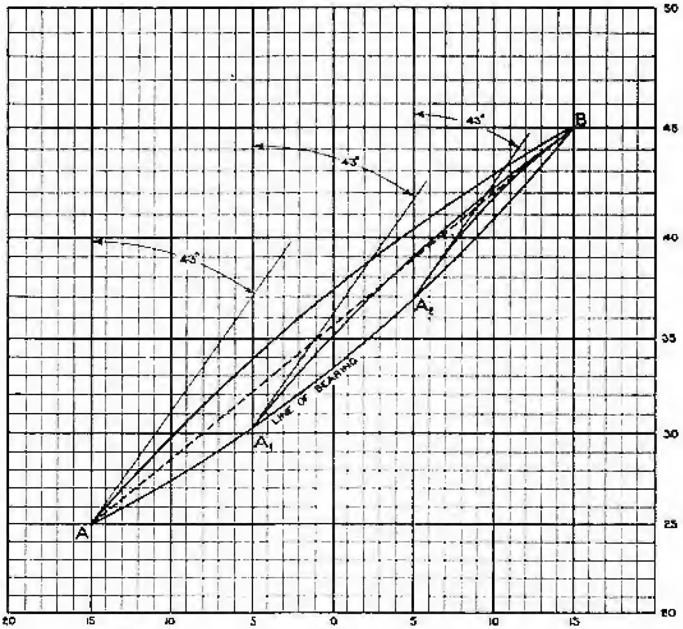


Fig. 245.—Line of Constant Bearing.

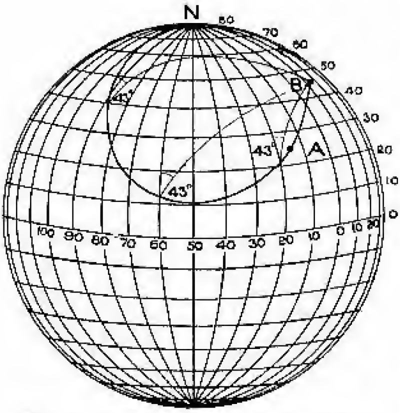


Fig. 246.—43° Line of Bearing with Respect to B.

that the lines of bearing are straight, but on the other hand the chart has to be specially drawn for the district, and is only correct for two points. The Mercator's chart has the disadvantage that lines of bearing are curves, which have to be carefully plotted by a rather laborious process, but against this are the advantages that Mercator's charts are almost universally procurable, and the lines of bearing may be drawn for as many stations as required.

THE CONICAL PROJECTION

The Simple Conical Projection. Referring again to the method of making a projection from a globe mentioned on pages 260 and 264, suppose, now, that the projection be made on to a cone, the axis of which passes through the poles as in Fig. 247. The cone will make contact with the globe along a parallel of latitude, this so-called **standard parallel** depending on the vertex angle of the cone.

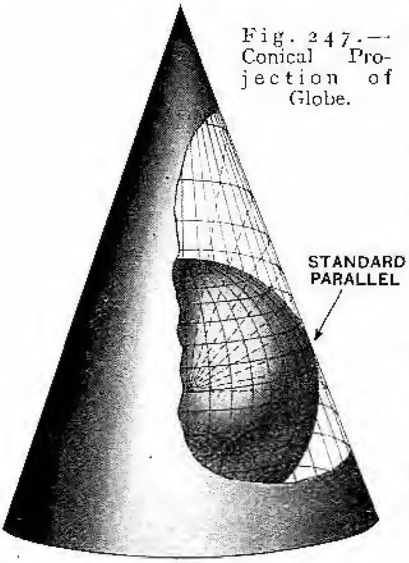


Fig. 247.—Conical Projection of Globe.

When the cone is opened out, or developed, it will appear as in Fig. 248, in which the parallels of latitude are arcs of concentric circles and the meridians are straight lines converging to the apex of the sector of the circle. Distances are correctly rendered along the standard parallel but elsewhere have varying scales.

Special Cases of the Simple Conical Projection. It is interesting to note that when the vertex angle of the cone is increased to 180° and the "cone"

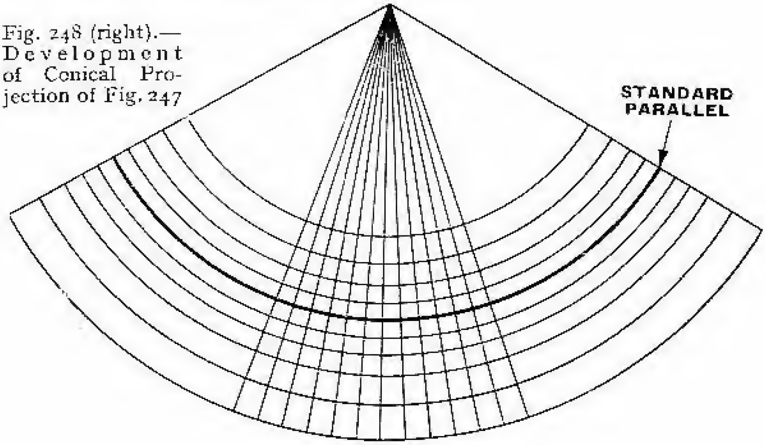


Fig. 248 (right).—Development of Conical Projection of Fig. 247

becomes a plane, the projection is the gnomonic one with the point of contact at the pole. When the vertex angle is zero, the "cone" becomes a cylinder and the projection is the simple cylindrical of Fig. 236.

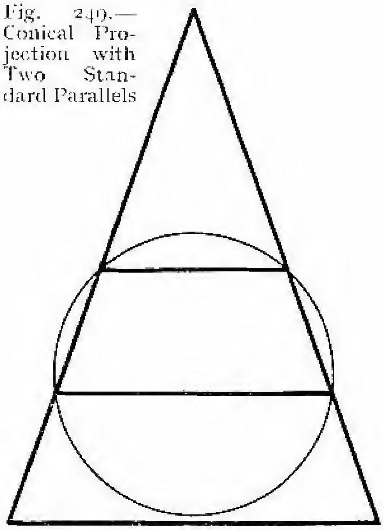


Fig. 249.—Conical Projection with Two Standard Parallels

The Conical Projection with Two Standard Parallels. If two standard parallels instead of one are chosen, an annular portion of the globe will be outside the cone as in Fig. 249, and again the parallels are concentric circular arcs, and the meridians convergent straight lines. This projection is an improvement on the simple conical one in that distances are correctly rendered along two instead of only one parallel, and the distortion is somewhat less, since the surfaces of the cone and globe are in general closer together over a larger area than in the simple conical case.

Neither of these projections is of particular use for D.F. work, but there is a third projection of the same class that is of greater value.

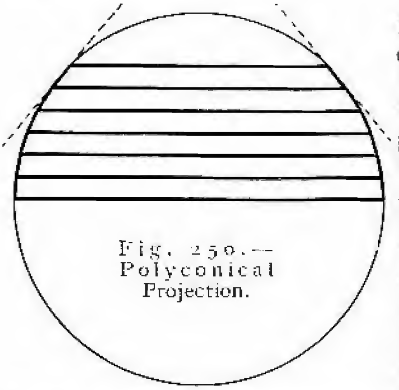


Fig. 250.—Polyconical Projection.

The Simple Polyconical Projection. Here, the principle of the conical projection with two standard parallels is extended until the portion of the globe, which it is required to represent, becomes made up of a series of truncated cones as in Fig. 250. Further, suppose the number of these truncated cones to be increased until the shape of the globe is again almost spherical. This projection cannot be developed as a whole surface but will appear as a series of incomplete rings as in Fig. 251, in which the parallels are circular arcs, though not concentric circles. The meridian chosen for the **central meridian** remains straight, but since the meridians are made of short sections of straight lines, all of which are part of different conical surfaces, they will develop as curved lines (assuming an infinite number of cones), and will, moreover, not cut the parallels at right angles.

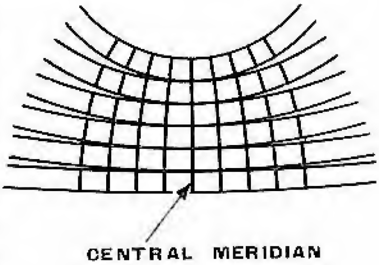


Fig. 251. Development of Polyconical Projection.

The sketch of Fig. 251 is, of course, very crude, but is intended to show, by the divergence of the opened-out rings, where the distortion in the projection will occur.

This projection has many modifications that have been used in important maps, among which may be mentioned the International Map of the whole world on a scale of 1/1,000,000 and war maps used by the Allied Forces in 1914-1918.

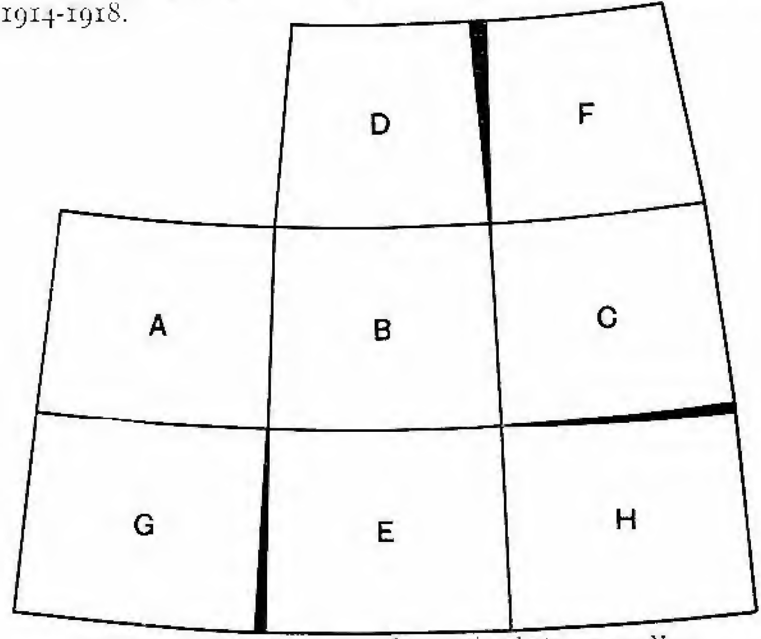


Fig. 252.—Adjacent Sheets of International 1/1,000,000 Map.

The International 1/1,000,000 Map. The sheets that go to make up this series extend over 4° of latitude and 6° of longitude in low latitudes and over 12° of longitude in high latitudes. The polyconical projection is modified so as to make the meridians at the edges of the sheets straight lines, and thus adjacent sheets east and west may be joined together as, for instance, A, B and C in Fig. 252. Again, since the radius of curvature of the lower boundary parallel on one sheet is the same as that of the same parallel at the top of the next sheet below it in the series, they may be joined together in a north and south direction as in the case of D, B and E. The whole map is not, however, a single projection, each sheet being projected for its own geographical position, as a result of which the intermediate sheets F, G, H, etc., will not fit, a space being left along one or other of their borders. The gaps are exaggerated in Fig. 252 but are enough to prevent the sheets being accurately joined to form a large wall map.

A disadvantage of each sheet being a separate projection is that courses and tracks cannot be continued from one sheet to another, even though the sheets appear to join one another satisfactorily. Advantages of the projection are that it is nearly orthomorphic (small areas have correct shape) and nearly orthodromic (Great Circles represented by straight lines). For navigational purposes bearings may be read off without appreciable errors to the limits of the sheet, and the maps have thus very considerable uses for D.F. work.

The scale is 15.78 miles to one inch and, in addition to the original series of sheets, separate ones on the same style have been made for Great Britain, by the Ordnance Survey Department, Sheet No. 2 of this set containing England and Wales.

BRITISH ORDNANCE SURVEY MAPS

In Chapter 17, when describing the geographical method of obtaining the direction of the meridian through a shore D.F. station, the use of an Ordnance Survey is involved, and a few notes on this series of maps may be of interest.

The 6-inch and 25-inch maps of the present survey are on what is known as a Projection by Rectangular Co-Ordinates or Cassini's projection, covering the area of a single county, or group of counties, to such an extent that no sheet lies more than 75 miles from a central meridian. The maximum scale error in a north and south direction is 1 part in 5,000, which is considerably less than the shrinkage or expansion of paper and would not be likely to cause any error when using the maps for D.F. purposes.

There is one characteristic of the maps, however, which can be and has been productive of errors which are entirely due to the carelessness or ignorance of the user. In these maps, the meridians, whilst appearing straight, are actually curves of very large radius, the change of slope on any single 6 inch sheet not exceeding five seconds of arc. This, of course, is quite inappreciable in any graphical use but in certain parts of the projection the convergence between a meridian and the edge of the sheet may amount to 1° 30′. When using the survey maps to obtain the direction of the meridian (page 723), care should, therefore, always be taken to make use of the scale of longitude, which is marked along the upper and lower margins, and not to assume that the meridian is parallel to the edge of the sheet.

The Ordnance Survey maps on scales of one inch or less to the mile employ the Transverse Mercator's or Lambert's first projection as a projection covering the whole country, and in this case again the convergence occurs between the meridian and the margin of the map. These maps may be used in the calibration of D.F. installations provided the precautions mentioned in the preceding paragraph are observed.

CHAPTER 9

THE SHORE OR AIRCRAFT GROUND STATION D.F.

Many of the factors of which account must be taken when erecting a shore D.F. station are common to all wireless receiving stations, but a number of additional precautions have to be taken which are peculiar to this branch of reception. Having decided upon the locality of the station from the point of view of its zone of action, the neighbourhood must be carefully inspected for a suitable site, and, if possible, for one or two alternative sites in case the first should develop unexpected disadvantages when tried out. It is an advantage for the direction of the meridian through the ultimate site to be known for the purpose of calibration, and the geographical position of the station is required to at least the same degree of accuracy with which it is hoped to operate the system.

The aerial system needs more than ordinary care in construction and special points arise in the installation of the receiving apparatus. Finally, the station must be calibrated to ensure that bearings are correctly rendered from all directions.

Systems of D.F. in Use. In Great Britain, the Bellini-Tosi system with either closed loops or the Adcock aerial is used almost exclusively for coast stations for ship work, and also for aircraft ground D.F. stations. Quite apart from the advantages of the Adcock aerial for the reduction of polarization errors, the large aerial of either form of B-T lay-out, together with the light moving parts of the radiogoniometer which can be conveniently arranged near the receiver, microphone and transmitting key, are well adapted to the requirements of accuracy and speed of operation together with stability of calibration.

The rotating loop D.F. is extensively used in the U.S.A. coast stations and is popular in all parts of the world for ship installations, very large numbers of American, English and German D.F.'s of this type being used at sea. The rotating loop is also well suited for mobile work.

The bulk of this chapter is devoted to the technique of the

B-T closed loop and Adcock systems, the growing demand for D.F. on flying routes during dark hours making the latter system increasingly important.

CHOICE OF SITE

It frequently happens that a shore D.F. station is situated at an aerodrome, or near to an existing coastal transmitting station, so that the choice of site becomes simply a matter of suiting local conditions and the technical considerations mentioned below. If, however, a number of D.F. stations are to be erected to guard a harbour approach, or for the navigation of a difficult channel or an airway, then the problem becomes one of obtaining the maximum accuracy over the greatest area with the smallest number of stations.

It is shown later, on page 552, that the best results are obtained when the " cut " from a pair of stations is at right angles, and that very acute cuts are of little value. On the other hand, really good sites for D.F. stations are rare, and valuable strategic positions, that would provide excellent cuts, are sometimes found to be either on rocky headlands which would be hopeless owing to screening and other errors, or on islands, where staff accommodation and land line communication present difficulties. The final arrangement usually resolves itself into a compromise between the navigational, administrative and technical ideals.

Technical Considerations. As mentioned in the introduction, the steadily increasing standard of accuracy of D.F. stations, coupled with the demand for a 24-hour service, have added greatly to the difficulties of those responsible for the installation, and particularly has the decision regarding the suitability of any given site become a task for the expert.

Probably the equipment demanding the most exacting site specification is the aerodrome ground station D.F., and particularly if the Adcock aerial is to be used. This is not because this aerial system is more prone to errors than the closed loop, but because its selection implies a desire to reduce both day and night errors to an absolute minimum.

The ensuing notes may therefore be taken to apply chiefly to such an installation, though it will be clear to what extent the choice may be modified when using the rotating frame or closed loop B-T aerials, with their more limited field of use.

Preliminaries. Whether the D.F. be for aerodrome or for coastal work, one of the first things to be ascertained is whether the authorities, for whom it is being erected, wish the aerial to be placed on top of the aerodrome administrative buildings or on the site of a coastal transmitting and receiving station. Such sites have been stipulated in the past at important D.F. stations and have been used with moderate accuracy, employing closed loop B-T and rotating frame aerials. Their choice is, however, to be criticised for any type of D.F. aerial for reasons that are mentioned later, and particularly would such sites present almost overwhelming obstacles to the successful operation of an aerial having a low standard wave error.

Having moved away from the buildings, the latter at once become a huge obstruction until a distance of a wave length or so is reached (the aircraft wave band being 850 to 950 m.), and this raises the question as to which of the following alternatives shall be chosen for connecting the aerial system with the control office.

> (1) Radiogoniometer and receiver in the control office with the maximum permissible length of feeder between the former and the aerials, which may be up to about a kilometre. If, however, the aerodrome is found by trial to be on a really bad wireless site, this method may seriously limit the D.F. accuracy.
>
> (2) Aerials on a satisfactory distant site which is too far away to use aerial feeders, the radiogoniometer and receiver being therefore installed with the aerial and remotely controlled. The "tele-control" equipment for this lay-out, though practical, is very expensive, and is not in common use for D.F. purposes.
>
> (3) D.F. erected as a separate small station with telephonic communication with the control office. This may be more extravagant in staff in some cases, but it leaves complete freedom to select an ideal D.F. site.

An extensive test is an advantage with the closed loop D.F. and most desirable with the Adcock, before any guarantee of night accuracy can be given. If there are any geographical or geophysical obstacles such as mountains, discontinuities in the soil conductivity or strata of varying electrical constants, it is probable that the site will be found unsuitable for D.F. during the dark hours with the shielded "U" Adcock aerial, although fair daytime accuracy may be obtained with Adcock or closed loop.

It is an advantage in testing for an Adcock site to use both a closed loop and a temporary Adcock aerial. Observations may then be taken with both aerials under working conditions and, in the case of an aerodrome, bearings ought to be taken by day and night on aeroplanes at different heights and distances, flying in varying directions and using their normal transmitting equipment. In this respect it should be remembered that the type of aerial used and the speed of flight when using a trailing aerial have a marked effect on the polarization of the radiated wave and on the range and accuracy of the bearings obtainable. Unless, after averaging the results of several days and nights, the accuracy of the Adcock shows a gain over the closed loop of at least 5 : 1 or 6 : 1, the temporary site should be considered unsuitable and the tests repeated elsewhere.

Experience has shown that it is not always necessary to abandon an area because of residual errors in the Adcock system, as a shift of as little as a few hundred feet will sometimes effect the necessary improvement. The ability to recognize the suitability of a site and the causes of residual errors in the minimum time, can only come with practice, but it will be realised that in rough country or in the case of an aerodrome in a manufacturing district that is thickly populated, and in which open spaces are scarce, the costs of the preliminary tests may be a considerable proportion of the cost of the complete installation, though this is unavoidable if accuracy is required. The tendered price for such a D.F. might reasonably contain a clause covering this point.

Fortunately the same difficulty is not usually met in the choice of an adequate site for a coastal D.F. station, as the received transmissions are travelling over the almost ideally even and uniformly conducting sea, though it remains necessary to ensure that the actual aerial site is reasonably good in other respects.

Terrain. As will be found below, under the heading of "Sub-Strata," a plain with a perfectly level surface and no visible obstructions for several wave lengths in any direction may, in exceptional circumstances, prove to be productive of night errors, whilst mountainous country can always be relied upon to be troublesome. In some parts of Switzerland, for instance, there has been found to exist a limiting accuracy of 10° or so.

In Scotland, similar effects have been observed by B.B.C. engineers when measuring field intensities and directions of B.B.C. transmitters. Comparatively sudden changes of field strength in the ratio of 2 : 1 have been accompanied, as might be expected, by equally erratic bearings and in the Grampian Hills a position was noted where the bearing of a transmitter showed a constant day to day error of 13°, indicating a form of enforced lateral deviation due to the wave being guided along some oblique valley, whilst hills obscured the direct path.

Permanent errors of this kind may sometimes be allowed for in a D.F. station, after sufficient confirmation has been gained as to their stability.

Apart from actually mountainous country, sudden changes in the nature of the surface of the ground, such as a line of rocks, will produce errors due to reflection if they are behind the station, and a site chosen at the edge of cliffs or inland rocks is unlikely to give reliable results. The accuracy of a D.F. erected on high ground near the edge of cliffs has been noted to vary with wave length when the cliffs intervened in the path of the wave and it is advisable in such cases to fix the aerial site at least a wave length from the cliff edge if possible.

Actually a site on a plateau in the centre of mountainous country has, on occasion, provided a reasonably good calibration, and if a remotely controlled equipment or a separately staffed D.F. station is permissible some miles from the desired site, this may prove a solution.

Coast refraction has already been mentioned on page 184, and careful attention must always be given to this matter when calibrating or choosing the site for a coastal D.F. Errors of a similar nature may also be experienced over land when the path of the wave crosses obliquely a change in the nature of the conducting surface over which it is travelling.

Soil Conductivity. Any aerial system that depends for its successful performance on a good earth connection, must be erected on a soil of high conductivity, extensive in both area and depth. The mere burying of earth plates a little deeper than usual is no solution, as in the extreme case of the station being built on a deep bed of dry sand, the wave may penetrate to a depth equal to a large fraction of a wave length, and the aerial and earth system are, to all intents and purposes, erected in mid-air. In addition to dry sand, certain forms of rock and volcanic lava are very poor conductors and conductive earthing becomes impracticable.

With these conditions, there is also a poor coefficient of reflection and a weak reflected ray, so that the performance of the aerial may vary greatly from that obtained on a good conducting earth and can best be found by trial.

Sub-Strata and Buried Conductors. In view of the penetration of the wave below the surface of a poorly conducting soil, it becomes important that there shall be no conducting strata that slant upwards and outcrop on the site.

Such strata under the aerial system would cause asymmetry in the aerial, whether it be an Adcock or closed loop, and would be liable to produce different intensities and angles of reflected ray, depending upon the direction of arrival of the wave front.

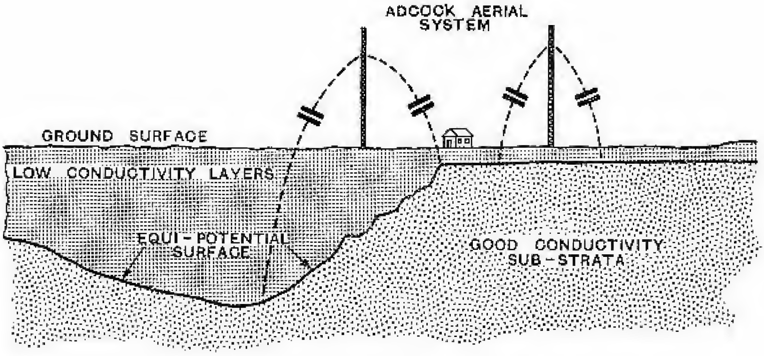


Fig. 253.—Uneven sub-strata below the surface of a D.F. site.

Conducting strata below the surface and at a distance from the aerial behave as surface obstructions to an extent depending upon the soil conductivity, and Fig. 253 illustrates how an uneven highly conducting layer may exist below a level top soil of low conductivity. This results not only in unequal effective heights of the vertical aerial elements but also produces unsymmetrical capacity to " earth " around each element and hence unsymmetrical polar diagrams of reception. An open aerial in a situation such as that on the left, in the figure, would have marked directional properties, for reflected rays, which might well vary with the angle of incidence. As mentioned above, a small change in the position of the aerials will sometimes effect a great improvement and in this instance a move to the right would probably have this effect.

In the case of the closed loop aerial, the top horizontal element forms a low resistance " short circuit " to the high impedance paths from the vertical elements to earth, indicated by the condensers in Fig. 253, and this results in a far more uniform current distribution throughout the aerial system, making it less susceptible to the effects of soil conductivity.

The burying of cables or service pipes of any conducting material under the site must also be done with circumspection, and those approaching the centre of the aerial system should be buried at least as deeply as the bottom of the earth system, and at an angle of 45° to the planes of the closed loop B-T aerial and under one of the feeder cables of the Adcock system.

Very large distorted quadrantal error (page 353) may be caused by buried conductors, and in the case of an experimental rotating frame D.F., errors of +16° and −12° were observed at points of the scale 50° apart, due almost entirely to buried iron plates supporting a sewer duct under the site (2223) (2317).

Diversity Effect in Large Aerial Systems. In Adcock aerial systems for aircraft waves, the spacing between the vertical elements may be 200 to 300 feet and with the complex direct and reflected rays that are incident on the aerial it may frequently happen that the effective field at one vertical element is suffering some distortion that is less apparent in the case of its fellow vertical element. Discontinuities in strata, etc., below the aerial may accentuate the effect and so introduce errors or indefinite minima.

In short-wave commercial receiving stations, it is common practice to use two or even three aerial arrays, spaced several wave lengths apart, in order that signals may be available from one when fading is occurring on one or both of the others, and this is called **diversity reception.** The term **diversity effect** is sometimes borrowed for use in circumstances in which a single fairly extensive aerial array is operating in a distorted electromagnetic field, which upsets the ideal phase relations between the e.m.f.'s in the system. Obviously a tendency to diversity effect in a D.F. aerial is most undesirable and anything that may exaggerate it is to be avoided by selecting a foundation for the aerials that is as conductive and as homogeneous as possible. The effect is unlikely to occur on B-T or Adcock aerials since the spacings are normally less than a tenth of a wave length.

Surface Obstructions. A position for the aerials on an open plain with the nearest buildings or trees more than a wave length distant is seldom realised, although this may be considered to approach the ideal so far as surface obstructions are concerned. When the site is cramped and buildings exist within a small fraction of a wave length from the aerial, there is every probability of errors being produced.

T. L. Eckersley has suggested interpreting the effect of these obstructions in terms of the solid angle they subtend at the aerial, and has observed in actual cases that 2° to 3° seems to be the maximum permissible angle. Thus an aeroplane shed 200 feet wide by 75 feet high at a distance of

1,000 yards subtends an angle of about 4° and might be expected to cause day errors of 3° to 4° and night Adcock errors of perhaps 8° to 10°, whilst a more modest sized building of about half these dimensions at the same distance might have negligible effect. A rule of this kind is useful in a preliminary survey and also if, at a later date, it is desired to erect buildings in the neighbourhood of the D.F. site.

In the case of a closed loop B-T aerial, the effect of a single conductor near the aerial can sometimes be rectified in calibration in the way mentioned under "D.F. on a Transmitting Station Site" on page 359, but the standard of accuracy in such cases is below that usually demanded at the present day for shore installations.

In addition to compact conductors such as aeroplane sheds, and semi-conductors such as buildings and trees, there are also telephone lines, power transmission lines, railways and wire fencing, all of which must be avoided.

Smith-Rose and Barfield (2317) give the results of tests made with a portable D.F. at different distances from a set of telephone wires supported on poles. Beneath the wires, errors up to 70° were observed and these fell off rapidly with increasing distance but were still a few degrees at 120 feet distant. The errors were also found to vary from one instant to another, depending, it was thought, upon the circuit conditions of the telephone wires.

Railway metals are a notorious cause of errors, and a line that passed within a quarter of a mile of an aerodrome D.F. site was found to cause errors of 10° on the bearings of aeroplanes crossing the line at a distance of a mile or two, where the direction of the railway track and that of the aeroplane made an acute angle.

Another illustration of the above effect, in its relation to transmitting beacons, appears in (3320) in the form of a strip aerial photograph of the U.S. Bureau of Standards aerodrome at College Park, Maryland. The position of the theoretical line of the equi-signal course is shown for about a mile, near to which can be seen a railway track, whilst a white line indicates the equi-signal course actually measured. The distortion when the track comes near to the course is most marked.

Broadcasting receiving aerials should be treated with a certain amount of suspicion. Receiving aerials in the vicinity may not cause errors so long as they are not tuned to the wave length on which the D.F. is working, but if they are so tuned a variety of troubles may ensue, including errors in bearings and also distortion of the heart-shaped diagram (page 330).

Relation of Accuracy of Bearing and Distance of

Transmitter. At the beginning of this section it was mentioned that tests should be made on transmitters at varying distances, and the reason for this is that a correct calibration for a distance of say 10 miles in a given direction may be converted into a faulty one at 50 miles, due to contours and obstructions, coast refraction or similar causes. Again, if a ship be sheltered behind an island, there may be a sufficient deviation of the wave front to cause an error, whilst at double the distance in the same direction, the wave front, though still suffering distortion when passing the island, recovers its normal condition again in a few wave lengths just as a fast-flowing river recovers from the disturbing effect of a bridge pier (2602). Exactly similar effects have been observed in the case of bearings of aeroplane transmitters when mountains intervene in the path of the wave.

Re-Radiation. Distortion of bearings also results from the re-radiation from tall metal chimney stacks, steel towers supporting wireless aerials, lift cables or lightning conductors in tall buildings, which may have a natural period near to that at which the D.F. station is operating.

The question of re-radiation is not always as straightforward as this since vertically polarized waves may be re-radiated with horizontal components of electric force and vice versa, the mechanism whereby this occurs being analagous to that illustrated in Fig. 203 in connection with the shielded "U" Adcock aerial.

In the case of Adcock installations, re-radiation may also be instrumental in producing errors in connection with the obstructions near the site, as mentioned on page 289, and for this reason their effect may be far more noticeable at night, wheu they become energized by rays from the reflecting layers. These rays may be polarized in any direction and the secondary fields radiated by the obstruction will probably be capable of affecting the Adcock aerial elements, and causing either quadrature effect or actual sharply defined but distorted minima.

Electrical Interference. It should go without saying that the proximity of a wireless transmitting station may cause endless trouble by jamming or may cause distortion if very close to the D.F. and tuned to the D.F. wave length or near it.

Power mains are another frequent source of interference, and D.C. mains are quite as bad as A.C. The D.F. is usually equipped with a high-gain R.F. amplifier and possibly audio-frequency magnification as well, so that the ripples of current due to bad commutation in an adjacent D.C. main may easily produce considerable noise in the telephone receivers. This type of disturbance is almost fatal to accurate direction finding, as the noise will usually have a definite direction and upsets the taking of swing bearings. Provided that the offending machine be accessible to the person erecting the D.F. station, it is often possible to reduce the noise due to bad commutation of either a motor or generator by means of condensers, lamps and chokes suitably connected across the brushes and to earth. Wherever possible power mains should be armoured and buried if it is necessary that they should be brought near to the station.

High-voltage transmission lines may also be troublesome owing to brushing and other effects, though the possibility of this type of fault is so well recognized now due to its interference with broadcast reception, that it will rarely be encountered at distances within which the lines can be tolerated as obstructions.

An aerial close to a main road may suffer from motor car ignition interference, though this is improbable except on short waves, in which circumstances it does become a serious problem. It may be noted, however, that on a direction finder with a modest R.F. gain, bearings have been taken on aeroplanes with unshielded ignition, when flying at a distance of a mile or two, the receiver being tuned to 300 m. Aircraft therefore cannot be ignored as a source of interference but are likely to cause less trouble on medium waves than on short waves.

D.F. on Transmitting Station Site. It may sometimes happen that a D.F. has to be erected on the actual site of a transmitter, and in such a case the best practice is to choose a position for the frame or the B-T loops which is as symmetrical as possible with respect to the main aerial and mast system and then to make trials. In some cases it is possible to get an all-round accuracy of within one degree under such conditions without the use of an error chart, but a good deal of ingenuity is required, particularly as the site may contain iron-roofed buildings, buried power mains, iron fencing and, of course, electrical machinery. In such a case provision must be made to disconnect the transmitting aerial *at the leading-in point* every time a bearing is taken. It should be particularly noted that the disconnection of the aerial at any other point, and particularly at its lower end where it is connected to earth, will usually be found to have little or no effect. The reason for this is that the aerial tuning inductances and other apparatus have such large capacities to the walls of the room and earth that appreciable currents are still produced in the aerial and cause violent distortion of bearings. A solenoid operated switch, with a two or three inch break, should be fitted close to the leading-in insulator and controlled by an additional contact on the "Send-Receive" switch or by some other device which renders the operation automatic. If, as is usually the case, the solenoid switch be fitted with an "economy resistance" which is inserted in series with the magnet winding when the switch operates, this may conveniently be made to take the form of a lamp which is placed alongside the "Send-Receive" switch in the receiving room. The lamp then acts as a pilot lamp and, by not glowing, gives warning in case the isolating switch fails for any reason.

It must, however, be emphasised that if a D.F. station is intended for important work such as the supply of bearings to aircraft or to ships at sea, where lives depend on the accuracy and reliability of the installation, it is a wrong policy to erect the D.F. on a site which is in many ways utterly unsuitable and full of potential sources of distortion of bearings.

Closed Loop B-T Aerials on the Roof of a Building. In Figs. 262 and 263 are shown methods adopted for rigging B-T loops over or on the roofs of buildings, as, for instance, at airports. Although not desirable sites, the aerials on a roof can be made to give a good performance and, in any case, such a location is doubtless better than any other that could be found within a radius of 1,000 to 2,000 feet owing to the obstruction offered by the buildings as soon as the aerial is brought down to ground level.

The primary consideration is a good earth connection, or equi-potential surface, and copper strip should be run from the receiving point, under the centre of the aerials if possible, to the four corners of the building and thence down to buried earth plates.

The steel frame of a building will usually be unsatisfactory as an earth connection as it does not form a low impedance path. The steel is presumably embedded in concrete at ground level and therefore mainly insulated except for chance earth connection through service pipes and cables, etc. The result of this is the possibility of noises and also of a high resistance earth connection that may be badly unsymmetrical with respect to the aerials.

The Reversibility Theorem. On page 197 the theorem of reversibility was mentioned with respect to the propagation of electromagnetic waves between two points. Whilst the selection of sites for directive beacon transmitters is not dealt with in Chapters 12 and 15 it may be mentioned that reversibility is equally applicable to local errors so that much of what has been said above applies with equal force to a transmitting beacon site. (2901).

The following references also bear on the subject of choice of site, etc., and may be read with advantage. (2013), (2801), (2901), (2907), (2223).

Fixing the Geographical Position of the Site. In the British Isles the most simple method of finding the latitude and longitude of any place is by reference to the Ordnance Survey Maps or Admiralty Charts, but no other map should be used unless published by a reliable authority. Unless the site has been chosen in a particularly barren locality, there will rarely be any great difficulty in finding the exact position of the station on the Survey map, but, where doubt exists, the method of finding the direction of the meridian through the site, which is explained on page 732, may be adapted to find the position of the station by the "triangulation" methods of ordinary surveying. This process corresponds exactly to that of a "Fix by Cross Bearings on Short-Range Stations," given on page 610, except that, of course, there is no movement of the ship to be taken into account and there must be no "cocked hat" when these optical bearings are plotted on the map. If the lines do not intersect exactly at one point, the bearings should be checked and re-checked until consistent results are obtained.

In countries where reliable maps on a suitable scale are not available, astronomical methods of finding the latitude and longitude are practically the only alternative. It must be remembered that nautical charts are procurable for all parts of the world, and in some cases a process of triangulation, using beacons, lights, etc., marked on the charts may give consistent results which enable the position of the station to be found when it is near the coast. In general the astronomical method is to be preferred and the direction of true North may be found at the same time.

Correct Orientation of Station or Aerial System. In order that the bearings as determined by the D.F. may be *true* bearings, it is necessary to determine the plane of the meridian through the site, and then so to adjust the pointer of the apparatus that it reads 0° on the scale for signals incident from the direction of true North. In the case of small rotating frames it is not a very simple matter to make these adjustments as the electrical axis of the solenoid or box form of frame does not always coincide with the geometrical axis, and it is more usual to rely upon a calibration obtained by bearings taken upon transmitting stations, the positions of which are accurately known, or else a portable transmitting set is used. In the latter case it becomes necessary to know the true bearing of the portable station, and this, particularly in the case of coast stations, may conveniently be found by means of a theodolite or sextant by methods to be described later.

In the B-T and Adcock system, it is usual to erect the aerials in North-South and East-West directions respectively, after which it is a very simple process to make the necessary adjustments in the radiogoniometer in order that it shall read true bearings.

Several methods of finding the direction of true North are described in Chapter 17.

Given a large enough number of distant stations on which to take bearings, or a portable transmitting station, the position of which can be found accurately for any required scale reading, there is no necessity to lay out the B-T aerials in any special directions; but if unsuspected freak conditions are found to exist when tests are made, it is a great advantage to have a reliable standard for calibration.

Rotation of Aerial System. In the case of the closed loop B-T, a condition may arise which nullifies this careful orientation of the loops. Under "The Error Curve" on page 353 there is mentioned the possibility of quadrantal error on an

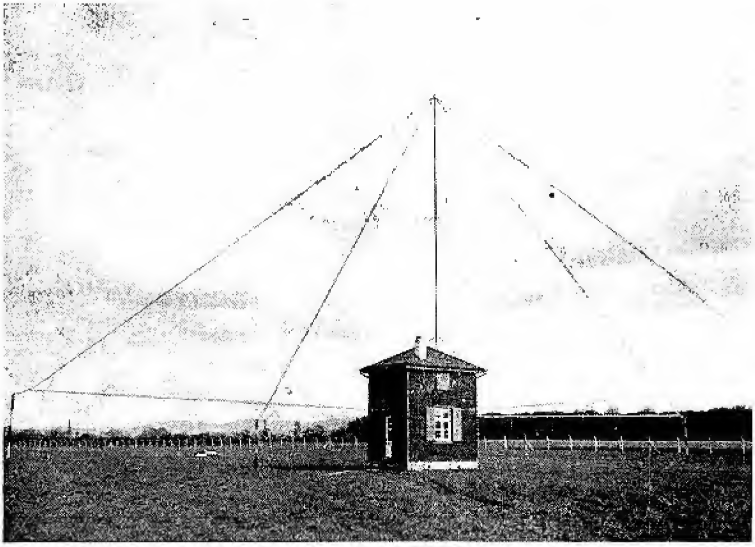


Fig. 254.—Triangular B-T Aerials with Single Mast and Corner Posts.

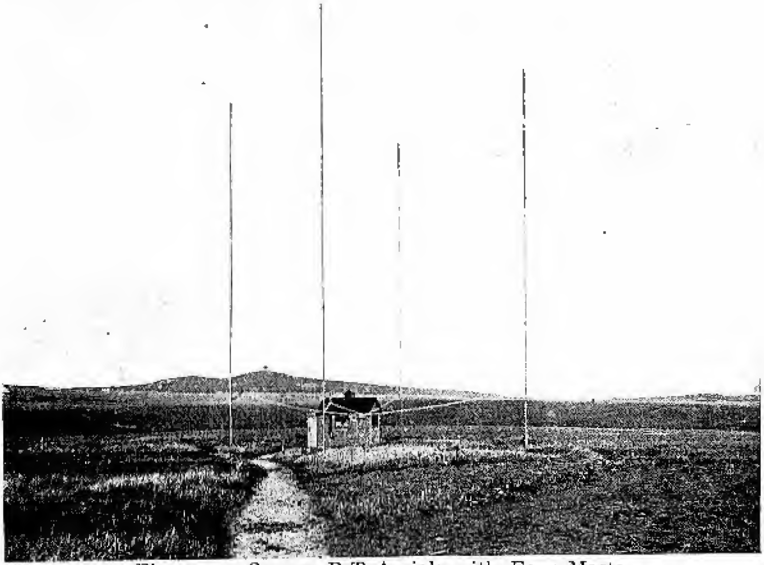


Fig. 255.—Square B-T Aerials with Four Masts.

imperfect site, and in the elimination of this it may be necessary to swing the whole aerial system. This need not be anticipated on a site free from obstacles, and even if it should be necessary to rotate the loops, time will not have been wasted as a North-South datum line is a useful adjunct to any receiving station.

THE B-T CLOSED LOOP AERIAL LAYOUT

A B-T station will usually take the form shown in Fig. 254, the two triangular aerials being supported from a single mast at the centre. There may be small masts to support the outer ends of the aerials with a view to stiffening them, or these outer masts may be high enough to give an appreciable super elevation of the outer ends of the loops, rendering them less liable to be affected by uneven ground or buildings and also giving head room. They were more common with tuned loops. Fig. 255 shows a square form of loop in which four masts are used ; but this is not in common use owing to the cost and also because the single centre mast is quite effective. In certain sites it is inconvenient to erect a mast at the exact spot selected for the aerial system and may even be more practical to put up two masts in open ground on either side of the site and to make use of a jumper stay to sling the B-T aerials in the way which is sometimes used in ship installations. A similar construction may be advisable when a B-T aerial has to be rigged on a transmitting station site, and a sketch of such a scheme is shown in Fig. 256.

Whatever may be the type of construction decided upon, the station consists essentially of two frame aerials at right angles, with leads running from the centre points of the bases of the aerials to the receiving building, which is, when possible, placed within a few feet of the aerials.

Laying out the Site of a B-T Station. If a theodolite, engineer's transit or sextant has been used for finding the direction of North at the site, the remainder of the work of laying out the position of the corner masts or anchor stakes, etc., can be carried out very rapidly and requires no further remark. If, on the other hand, no optical instruments are available, it is still a comparatively simple matter to lay out the site by the methods of field geometry. Right angles may be measured off by this means to any desired accuracy, and the use of ranging poles for the purpose of alignment is one of the most accurate processes in surveying.

Suppose that in Fig. 257 stakes have been inserted at O and N, marking respectively the proposed position of the mast and the direction of North from the mast. Replace each

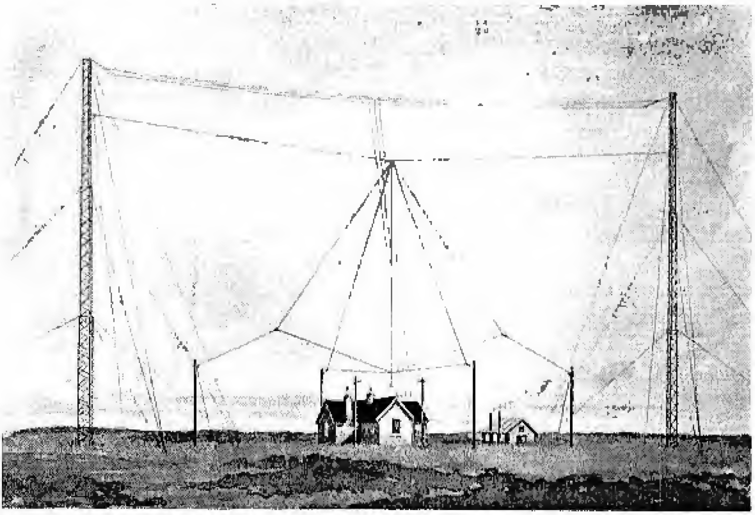


Fig. 256.—Triangular B-T Aerials Rigged from Jumper Stay between Transmitting Aerial Masts.

of these stakes by a ranging pole (a straight wooden rod about six or seven feet long, an inch or so in diameter and having a point at one end so that it may be stuck into the ground). It will save further work if the distance ON has been made equal to the radius of the aerial anchors or corner masts. Now measure off OS equal to ON and insert a ranging pole at S in such a position that when the three poles are viewed in line from a considerable distance, the near pole completely eclipses the other two. A pair of field glasses may, with advantage, be used for this work, when a small fraction of an inch of error in the position of the pole S can be detected.

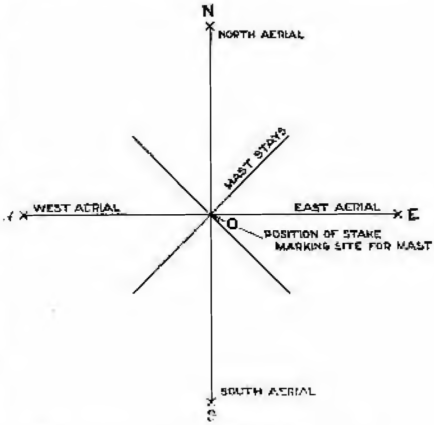


Fig. 257.—Plan of B-T Triangular Aerial System.

The direction of the line EW can now be found in several ways, one of the simplest being to make use of the fact that in a triangle, the sides of which are in the proportion 3 : 4 : 5, the 3 and 4 sides enclose a right angle. These and various other methods of geometry are applicable and, having obtained the positions of E and W, ranging poles should be inserted at these positions and the line EOW inspected. If these poles are in alignment and if the measurements of the sides of the square and also of the diagonals are consistent, the lay-out will have all the accuracy required.

The same scrupulous care need not be taken in the case of the mast stays, except for large permanent stations, but care in laying out the aerials is well repaid.

The method is equally applicable to an Adcock layout, though in an important station, a theodolite or engineer's transit will normally be available.

B-T LOOP AERIAL SYSTEMS: THEIR CONSTRUCTION, INSULATION AND METHOD OF SUPPORT

Whilst the small shielded loops of the type shown in Fig. 338 are sometimes used in shore installations, the larger unshielded loop is more usual and methods, more or less satisfactory, of rigging the two frames will probably present themselves to the reader who has had experience of the construction of any sort of aerials used in wireless work. Experience in practical direction finding work shows, however, that correct proportioning of the limbs of the aerials has a considerable effect upon the results obtained with the installation and some notes are given below on the dimensions and construction of the most common type of aerial used, namely, the triangular loop with the central mast 70 to 100 feet in height.

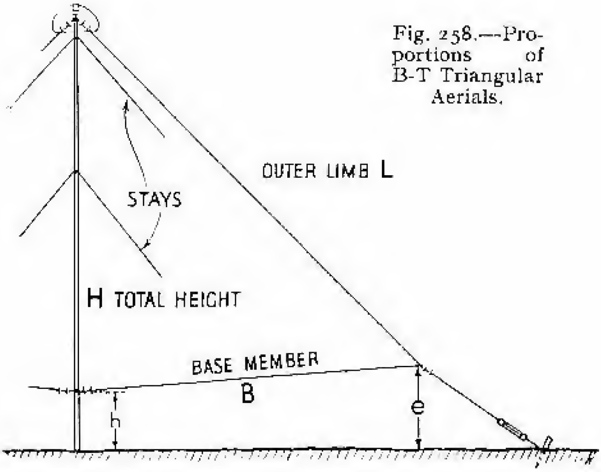


Fig. 258.—Proportions of B-T Triangular Aerials.

Triangular Frames. A number of factors govern the height of mast to be used on a station, and the height of the mast, in turn, governs the rest of the dimensions of the frames. If the range of the station is to be small, and particularly if the station be a temporary one, a 35 or 40 foot mast will probably be used. For longer ranges and stations of a semi-permanent nature a 70 foot mast is usual. Masts of 100 feet or more in height are generally permanent ones, and may be fitted with man halyards or pole steps in order that the aerials may be rigged after the erection of the mast itself. The cost of the mast and the area of the site become great if high masts are used, and there is also the chance that the natural wave length of the frames and field coils may be greater than the minimum wave to be received.

In Fig. 258 is shown a diagram of a triangular aerial in which the proportions of the various parts are as follows :

H = Total height of mast.
L = Length of outer limb of aerial.
B = Length of base limb of aerial = H or not less than $\frac{3}{4}$ H.
h = Height of base member at foot of mast = about 10 feet or less in the case of a very small mast.
e = Elevation of base member at outer end = *h* on a level site and anything up to say 2 *h* or more to avoid buildings, etc.

These proportions may be taken to represent average practice in the construction of triangular frames, and taking 70 feet as the height of the mast, the actual dimensions of the aerials would be as follows:

Height of mast	70 feet
Outer limb of aerial	90 ,,
Base limb	70 ,,
Height of base at foot of mast	10 ,,
Elevation of outer end of base limb	15 ,,

Total length of wire = 2 (70 + 90)
= 320 feet in actual frame.

In addition to this must be allowed 10 feet at the top of the mast for the cross-over, and, say, 12 feet for each of the leading-in wires to the receiving room, so that the total length of wire required for each aerial is 320 + (2 × 12) + 10 = 354 feet.

The natural wave length of such a loop is between two and two and a half times the length of wire. In the example just quoted the length of wire is 320 × 0·3048 = 97·5 m., whilst the measured wave length was found to be 233 m. or

$\frac{233}{97{\cdot}5} = 2{\cdot}39$ times the length of wire in the loop.

Other electrical constants of the aerial are:

Inductance of each loop	164 μhy.
Distributed capacity of each loop	0·00009 μfd.
Capacity to earth of complete aerial	0·0017 μfd.
D.C. resistance of each loop when using 7/19 silicon bronze wire	0·65 ohm.
H.F. resistance of each loop on wave length of 1,000 metres	2·0 ohms.

Construction of Aerial. Each frame should be made of a continuous length of wire which has no soldered joints. The wire of each frame should be of the same material and gauge, any standard aerial wire such as 7/19 or 7/22 silicon bronze being suitable for D.F. work. Although the span is rarely more than a fraction of that which occurs in the case of a large transmitting or receiving aerial, a strong wire is still desirable owing to the necessity for pulling the wires very taut after erection in order to prevent swaying in the wind, with consequent production of mutual induction or variation in the strength of signals. These effects will only be noticed with tuned or quadrature compensated aperiodic aerials.

Provision must be made at the masthead for supporting

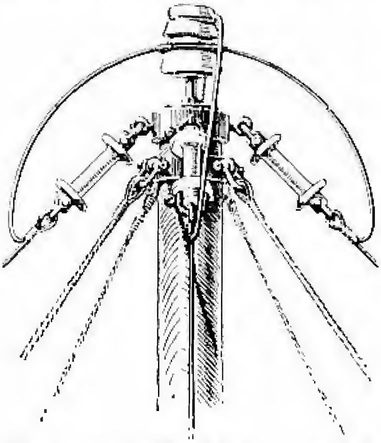


Fig. 259.—Masthead Arrangement of Triangular Frames on Light Mast.

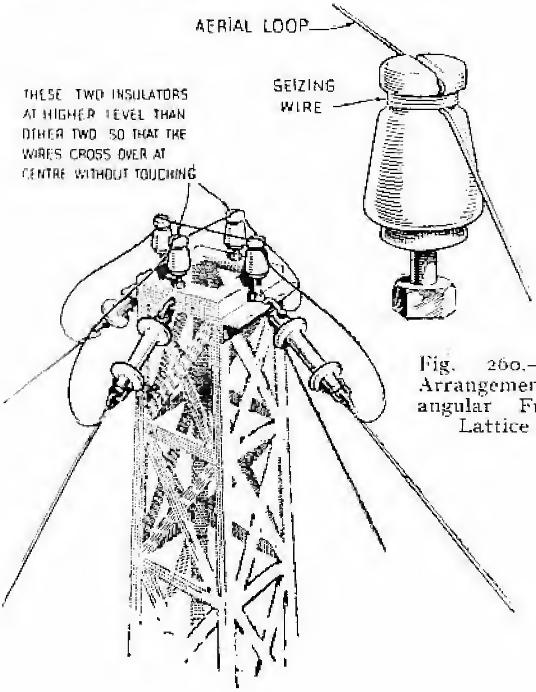

AERIAL LOOP
SEIZING WIRE
THESE TWO INSULATORS AT HIGHER LEVEL THAN OTHER TWO SO THAT THE WIRES CROSS OVER AT CENTRE WITHOUT TOUCHING

Fig. 260.—Masthead Arrangement of Triangular Frames on Lattice Tower.

the aerial cross-over insulator and also the strain insulators for the outer limbs of the frames. Fig. 259 shows a form of construction in which the two aerials are supported by porcelain strain insulators whilst the apexes of the loops are insulated from one another by means of a telegraph transposition insulator, which is either fitted to a mast cap or to a spindle which is screwed into the top of the mast. If the mast is a light one and not fitted with a man halyard, all this gear must be fixed before the mast is erected, and a good deal of care is necessary to ensure that nothing fouls in the process. Fig. 260 gives a method of crossing over the apexes of the two loops on a lattice tower.

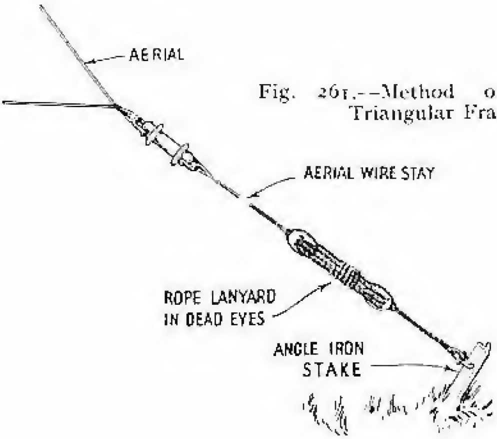


Fig. 261.—Method of Anchoring Triangular Frame.

Fig. 261 illustrates a way of tying back the ends of the base and outer limbs of the aerials. The rope halyard may be replaced by a rigging screw (turn-buckle) if desired ; but the aerial wire has a good deal of stretch in it, which means constant resplicing of a wire stay. Apart from this, the occasion hardly warrants a rigging screw. The aerials should never be stayed back entirely with rope, even if tarred, as there will always be a certain amount of shrinkage when it becomes wet, and trouble due to slackening during a dry spell.

An alternative method of securing the outer ends of the aerial is by means of a small mast as in Fig. 254. This allows a larger aerial to be rigged on the same area and also reduces the swaying in the wind. In the case of diamond-shaped aerials, the outer mast becomes almost essential. The diamond-shaped loop is not in general use except on sites where the ground is very uneven or where the aerials would otherwise run within a few feet of buildings, etc., in which case, if triangular loops were used, the difference in capacity between the earth and the respective base limbs would seriously affect bearings. This matter is dealt with again in reference to Fig. 325.

Good insulation, especially with tuned aerials, is very necessary, and it is advisable to use porcelain throughout if possible. The "dumb-bell" form of porcelain insulator shown in the above illustrations is a very satisfactory one, and an aerial constructed with this type should have an insulation resistance of 10 megohms under adverse weather conditions.

D.F. Aerials on Transmitting Station Site. In Fig. 256 was shown a method of rigging a pair of B-T loops from a jumper stay or triatic between two transmitting station masts, and Fig. 262 shows some details of the rigging. The jumper stay of one inch circumference wire rope is taken through blocks attached to the masts and brought down to concrete anchors. The stay, if several hundred feet long, must be broken in two or three places by insulators, or heavy currents will be induced during transmission. Special fittings are necessary in certain places, and suggestions for these are shown. If the site be an exposed one, everything in connection with the construction must be very robust. The centre stay should be of one-inch circumference wire rope and the aim in rigging the aerial should be to get the jumper stay pulled up tight and to take the strain on the centre stay, so that, when the four corners of the loop are stayed out, the apex insulator and the centre stay plate are both fairly rigid. If the jumper stay is not pulled up taut enough to put a good strain on the centre stay, then, when the aerials are rigged, the centre stay will slack off and the aerials themselves will take the greater part of the strain. In this case the whole construction will be insecure and there is a good chance of the aerials being broken in a gale. In the station shown in Fig. 256 the centre stay is split just below the stay plate and two stays are brought to anchors, one on either side of the building, it usually being impracticable to attach it to the roof of a building unless it be of steel construction.

B-T Loops Erected on a Roof. If B-T loops have to be rigged on a roof, as for example, on the buildings at an airport, it may be found difficult to get an adequate base length and in such a case multi-turn loops have been successfully used. A good earth connection will have been obtained for the receiving apparatus by means of copper strip connections as mentioned on page 292, and in the case of two-turn loops the field coil centre-point will be earth connected as a general rule. If three-turn loops are used, together with a central steel mast, the mid-point of the aerial wire may with advantage be connected to the mast head provided that the base of the mast has a strip connection to the wireless earth.

Methods of securing the outer ends of the loops will depend upon circumstances, but in the case of a flat roof, points can usually be found for the attachment of tension insulators, or additional base line and a suitable fixing can be obtained by using a form of boom under each of the four loop extremities,

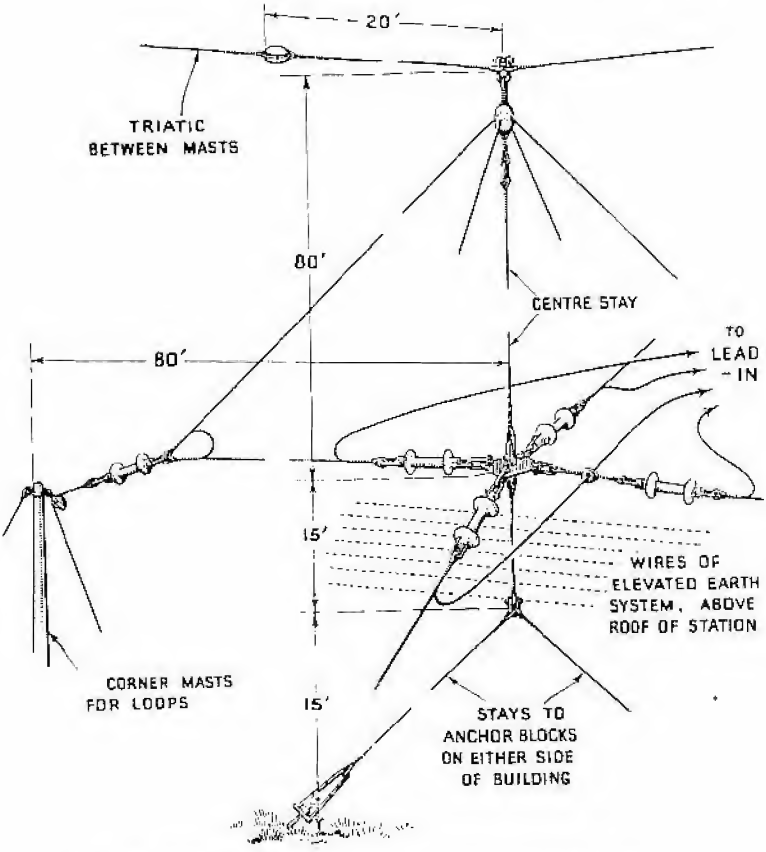

20′
TRIATIC BETWEEN MASTS
80′
CENTRE STAY
TO LEAD - IN
80′
15′
WIRES OF ELEVATED EARTH SYSTEM, ABOVE ROOF OF STATION
CORNER MASTS FOR LOOPS
15′
STAYS TO ANCHOR BLOCKS ON EITHER SIDE OF BUILDING

Fig. 262.—Details of Rigging of Frame in Fig. 256.

as in Fig. 263 which shows the control tower and B-T loops at the London Airport (Croydon).

Leading-in of the Aerials. The way in which the aerials are led from the foot of the mast to the receiving build-

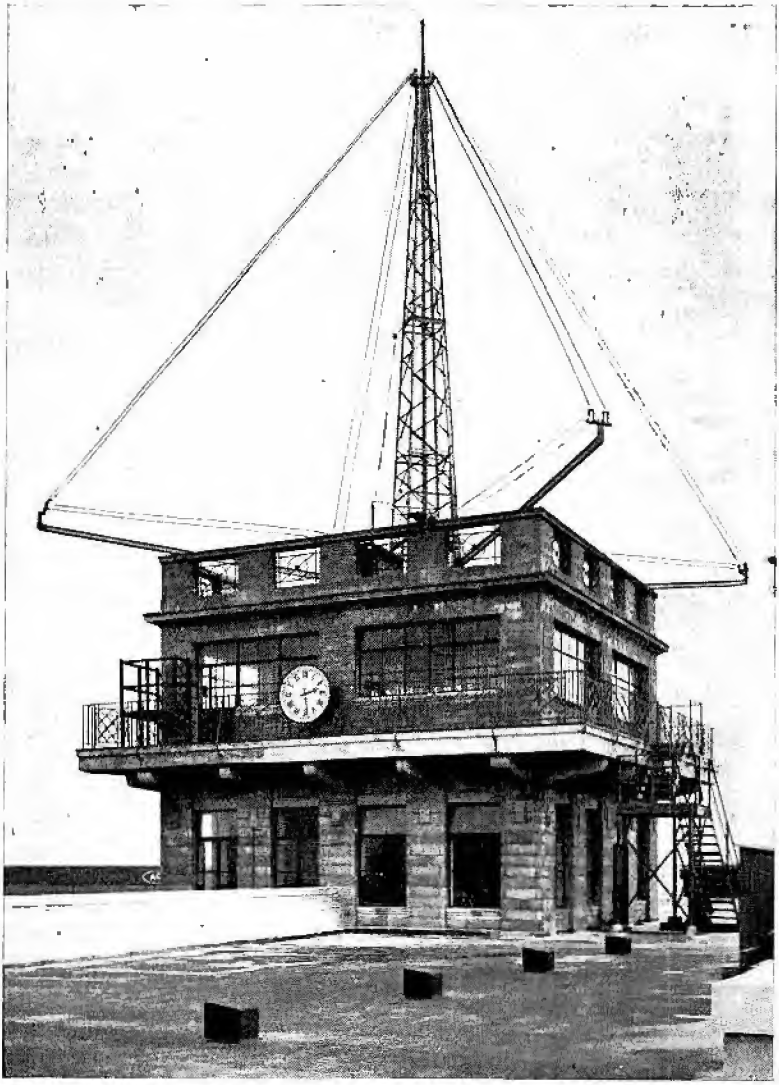


Fig. 263.—Use of Booms and Two-Turn Loops at London (Croydon) Airport D.F. (Marconi Co.).

ing will vary according to the type of station, and one of the best methods of leading in when using tuned aerials is as shown in Fig. 264. In making the aerials, enough " tail " is left to enable the lead-in to be a continuous length of wire with the aerial loop itself, and telegraph insulators are used for the support.

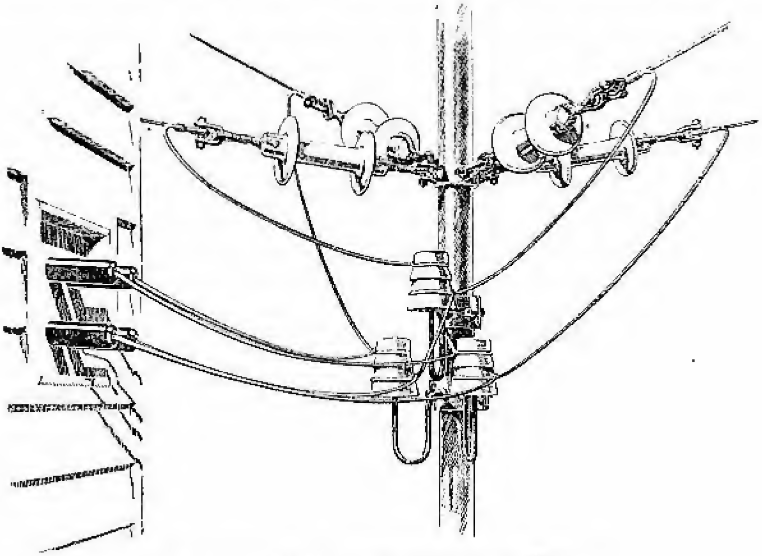


Fig. 264.—Short Lead-in for Tuned Frames.

If, for some reason, it is not possible to arrange a short lead-in, intermediate supports will be necessary, as in Fig. 265, which shows three of these posts and the lattice steel mast for the aerials. It will be seen that the four insulators on each post are arranged so that the points of attachment of the wires form a rectangle, and it is important that the two wires forming the leads from any one aerial loop should be at *diagonally opposite corners* of this rectangle. If, on the other hand, one pair of leads be attached to the top two insulators and the other pair to the lower ones, the planes of the small loops, represented by the pairs of leads, will be parallel for a considerable distance, and very appreciable coupling will exist between the aerial circuits.

The diagonal arrangement does not eliminate all the coupling unless the insulators are fixed in an exact square; for only in this case are the planes of the two loops exactly at right angles to one another.

A closer inspection of Fig. 265 will show that the four leads are rotated or **transposed** along the length of the lead-in, the wire from the top right hand insulator on the near post going to the bottom right hand insulator on the second post and to the bottom left hand of the third post, etc., and similarly with the remainder of the leads. Owing to the rotation of the wires it follows that any e.m.f. induced in one of the loops

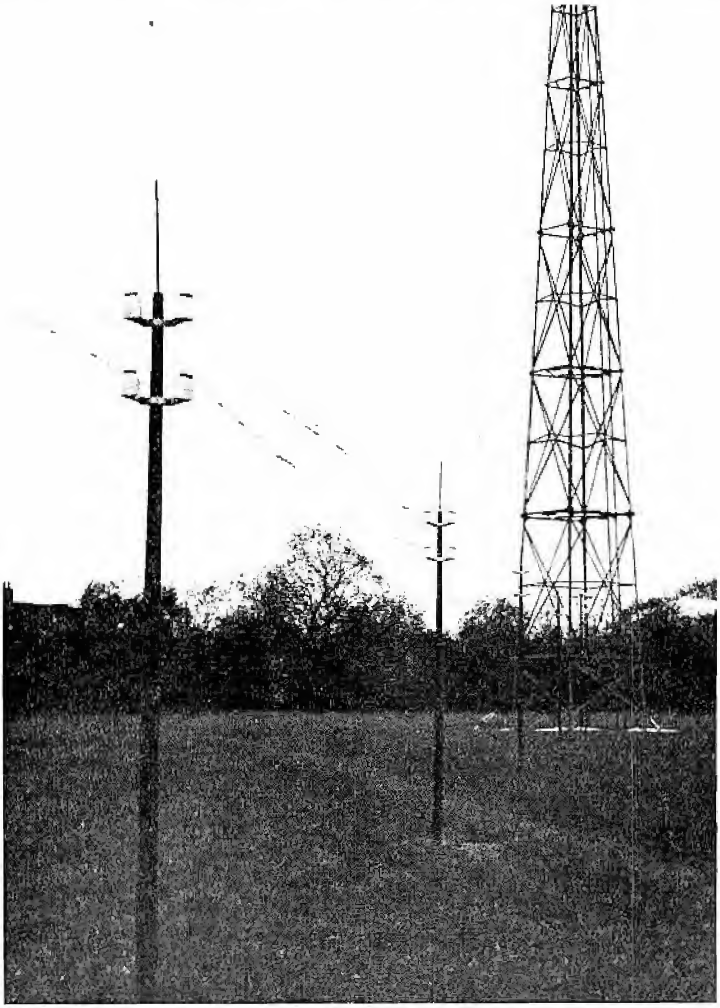


Fig. 265.—Long Lead-in Showing Transposition.

(formed by the pair of wires from one of the aerials) will be opposed by an equal e.m.f., induced in another section of the same loop, which is in the *opposite direction round the circuit.* This type of transposition is adapted from telephone practice where it is used to prevent interference between adjacent circuits.

Another advantage of transposing the wires of the lead-in is that the mean distance from the ground of all four wires is now the same and hence the capacity to earth of the four wires is constant. This has the effect of maintaining the electrical balance of the aerial circuits, which has been seen to be an important factor in the tuned aerial system, but is quite negligible with aperiodic loops.

The wires should be strained sufficiently tightly to prevent swaying in the wind, with consequent production of mutual induction or capacity between the loops, and for the same reason they should not be run too near to one another, as in this case the relative movements of the wires will have a proportionately greater effect. Between six inches and a foot is a suitable dimension for the horizontal or vertical distance between wires. It is advisable not to take the strain of the last section of the lead-in on insulators attached to the wall of a wooden receiving building, or trouble may be experienced owing to the noise, made by the vibration of the mast and aerials in the wind, being transferred to the receiving room.

The insulators should be of a similar pattern throughout, otherwise the varying leakage resistances of the insulators in wet weather may result in the two circuits having different dampings.

With aperiodic aerials, many more liberties may be taken, and with a 70 or 100 foot mast and triangular aerials, a lead-in of the form shown in Fig. 265 may be 50 or 75 feet in length and still give perfectly satisfactory results. In the case of a temporary station, high tension cable of the type used for the ignition systems of petrol engines may be used in an emergency, thus dispensing with all further insulation between the aerial base and the D.F. receiver. Such an arrangement is shown in Fig. 266.

Cables, of the type described on page 420 for use with ship installations, are also employed in shore stations where an open wire lead-in is undesirable but can only be used with aperiodic aerials. The use of transmission lines has also been mentioned on page 175 when the distance between the aerials and receiving room amounts to some hundreds of yards, but this is exceptional in the case of the B-T system, although more common practice with Adcock aerials.

With an elevated aerial, such as that shown in Figs. 256 and 262, it may be convenient to bring the wires down in the form of a cage with spreaders fixed at intervals as in Fig. 267. They may be taken to some standard form of telegraph insulators on a pole erected near to the point where the wires enter the receiving room.

The problem of the best way to take the wires through the wall of the receiving building has been tackled in many ways, but the best results are obtained by taking the aerial wire through an earthenware or porcelain tube, tilted downwards towards the outside, the ends of which are suitably protected from the weather. A view of this type of lead-in is shown in Fig. 264.

If desired, a partition insulator of some type can be used, but it introduces four screwed terminal connections in each aerial lead. This is undesirable, for if a high resistance fault occurs in the aerial circuit of an ordinary receiving station, the fact at once makes itself apparent by the weakening of signal strength; whilst on a D.F. station the signals from one frame become weaker than from the other, the " minimum " as heard in the telephones becomes first indefinite and then definitely wrong. If bearings are not being taken during the indefinite period the trouble may not be suspected for some time, and, before noticing the errors in bearings, a station might easily be the unwitting cause of wrong information being given to ships or aircraft concerning their positions. For this reason, the sight of the four ends of the actual aerial wires, attached to the radiogoniometer, and the knowledge that these wires are supported throughout by a good

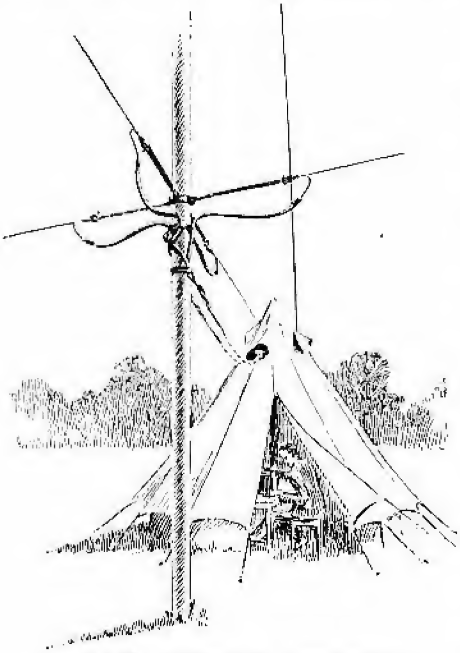


Fig. 266.—Temporary Lead-in for Aperiodic Frames.

design of porcelain insulator, inspires a good deal of confidence and reduces to a minimum the chances of trouble outside the receiving room.

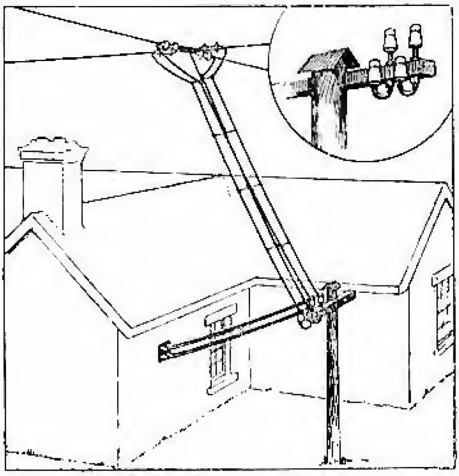


Fig. 267.—Cage Form of Lead-in from Elevated Loops.

The Earth System. No departure is necessary, in respect of the earth system, from the methods adopted for the non-directional receiving station. If the soil in the neighbourhood of the station is moist and of high conductivity, a satisfactory earth can be made by the use of two or three earth plates having a total area (one side) of say 30 square feet or so. It is well to remember that a number of obscure faults may be caused by a high resistance earth connection, and in an important D.F. station it is advisable to make use of a circle or semi-circle of galvanised iron plates buried in the ground at a radius of 10 to 15 feet. The plates may be soldered together to form one continuous sheet or/and individually to radial wires brought to an earthing bus-bar inside the building.

It is a wise precaution never to allow any other electrical connection to be made to the wireless earth, such as telephones, buzzer circuits, land line telegraphs, etc., as these not only introduce noises but they may also be the cause of actual errors in bearings if the resistance of the earth connection becomes high.

In the case of temporary stations, the wire gauze nets used for portable field wireless sets are satisfactory, and it is customary to put one length of gauze under each of the four lower limbs of the B-T aerials.

THE BURIED OR SHIELDED "U" TYPE ADCOCK AERIAL LAYOUT

The principle of the Adcock aerial has been explained in Chapters 6 and 7, together with some figures for the performance of the above type. Its method of construction when using a central receiving building on the site is described below, whilst the necessary modifications for use with extended feeders to a distant receiving point are dealt with on page 314.

The Marconi Adcock Aerial Installation. For the wave lengths used in marine and aircraft work, 600 to 1,000 m., the aerials are usually 75 or 100 feet high and are set at the corners of a square of 200 feet diagonal. Two opposite masts support, from a triatic, the auxiliary aerial for sense determination and the elimination of quadrature effects. The layout is the same as in Fig. 271, except that the receiving hut is placed at the centre of the system and the extended feeder junction box and quadrature compensating aerials are not used.

The aerials are usually set out north, south, east and west, but this is not essential. Since residual quadrantal error, if any, is never corrected by manipulation of the aerials, as is the case with the closed loops, there is no chance of their having to be moved subsequently on this account, so that the orientation is a matter of choice.

Aerials. The aerials may either be supported from wooden lattice masts or the more recent type of mast-aerial may be used as in Figs. 268 and 272. The latter is a lattice steel mast, insulated at its base and having stays broken up by insulators into lengths chosen so as not to resonate at a frequency, or a harmonic of any frequency, to be received.

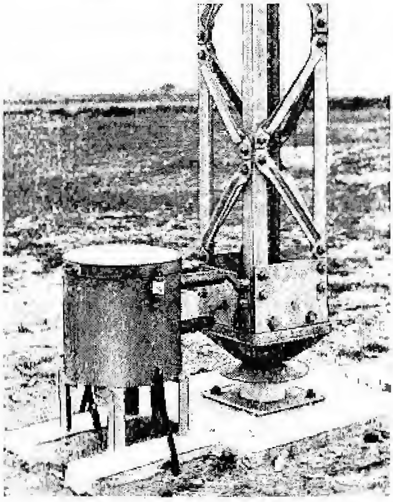


Fig. 268.—Base of Mast Aerial for Shielded U-type Adcock Aerial (see also Fig. 270) (Marconi Co.).

Whilst the mast aerial is structurally sound and convenient, it has the disadvantage that it presents a large area to rain storms, so that in the case of thundery conditions, the charges that accumulate on the mast due to charged raindrops cause interference to a greater extent than with the wire aerial.

The same effect may be produced by electrified sand particles during a sand storm and the phenomenon is known as **fizzly, rain static** or **sand static**. Serious jamming is caused at times but may be slightly reduced by painting the masts with insulating compound, although whatever type of aerial be used the effect cannot be entirely avoided with the very high gain receivers required for use in the Adcock system.

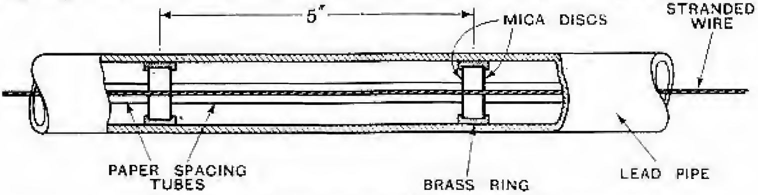


Fig. 269.—Cross Section of Concentric Feeder.

For the reasons mentioned on page 250, a high aerial is required for D.F. ranges up to 400 miles, and masts of 100 feet are desirable. In tropical countries, where reception is limited by atmospherics, the 75-foot mast is adequate.

Short Aerial Feeders. The concentric feeders for the normal layout, in which the radiogoniometer is at the centre of the four aerials, consist of a lead pipe of one inch internal diameter with a single inner stranded conductor. Fig. 269 shows the feeder in which mica discs are seen to support the conductor, being spaced by paper tubes. In the process of extruding the lead sheath, the mica discs are firmly gripped by the lead and so clamped in position.

To avoid damage by moisture during installation, the cable is cut to the required lengths by the makers, sealed into junction boxes at each end, and desiccated before being despatched.

The load presented at the base of a mast aerial of the type illustrated, is a capacity impedance of about 700 Ohms, whilst the surge impedance of the feeder is of the order of 200 Ohms, but the length of feeder is so short that no measurable loss is introduced by direct connection without matching. Similarly the copper and other losses are quite insignificant. Correct matching involves the expense of suitable transformers and balancing arrangements, and these are only used for long feeders necessitated by a receiving point which is at a distance from the aerial site.

When erected on soil of the requisite conductivity of about 10^{-13} c.g.s. units, the feeders are buried to a depth of 2 feet 6 inches and are brought vertically up through the floor of the receiving room to the radiogoniometer, and similarly at their other extremities where they enter the box at the base of the mast.

Earth System. The performance of the screened "U" and also that of the balanced-coupled system is largely dependent on the correct earthing arrangements, and when possible connections from the feeder sheath should be extended to a distance of four to five times the height of the mast radially from the receiving building or centre of the system, as shown in Fig. 207. This not only assists in reducing the accumulation of charges on the feeders in the vicinity of the vertical portions of the aerial, but also provides a screened route for control and power cables approaching the receiving building.

The extended earth consists of three No. 16 gauge copper wires buried to the same depth as the feeders and each soldered to an earth plate 6 feet by 2 feet.

Aircraft Obstruction Lamps. Obstruction lamps, when necessary, can be arranged to use the normal supply, carried

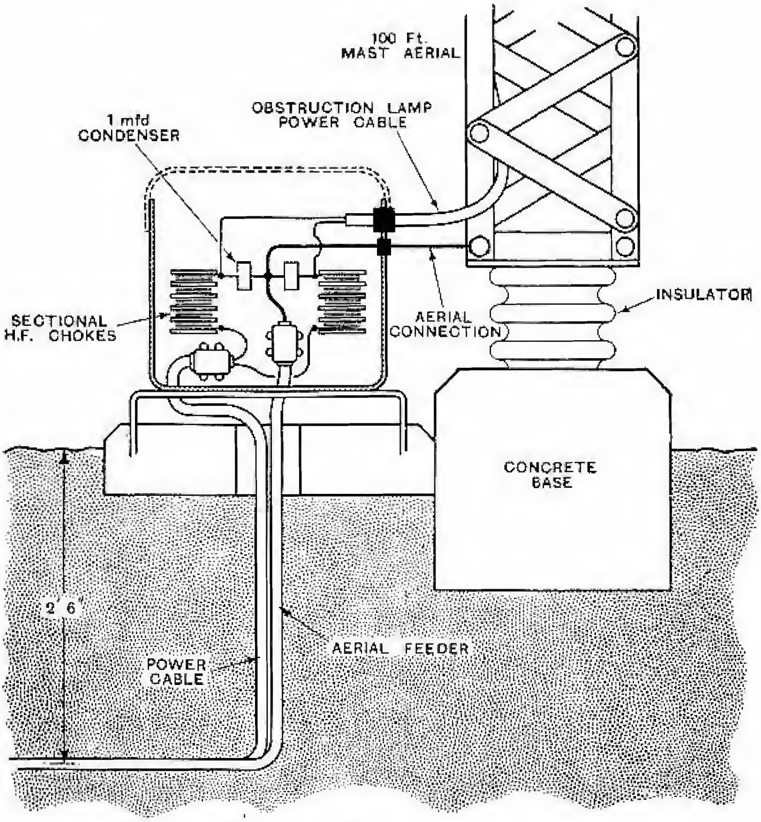


Fig. 270.—Details of Mast Aerial Base of Fig. 268 showing Provision for Aircraft Obstruction Lamp Power Supply.

up the mast in an armoured cable that is secured and bonded to the mast. At the base, the cable enters a suitable junction box, through an insulating bush, and the method of isolating the radio frequencies from the power mains in the case of 50 cycle A.C. supply, is shown in Fig. 270. The mains are taken through high-frequency chokes, wound in sections such that whilst offering high impedance to radio frequencies, they shall not resonate at any frequency used on the system. Across the load side of the chokes are two 1 mfd. condensers in series, the mid-point being connected to the base of the mast aerial. The whole of the lighting system is thus at aerial potential and forms a part of the aerial.

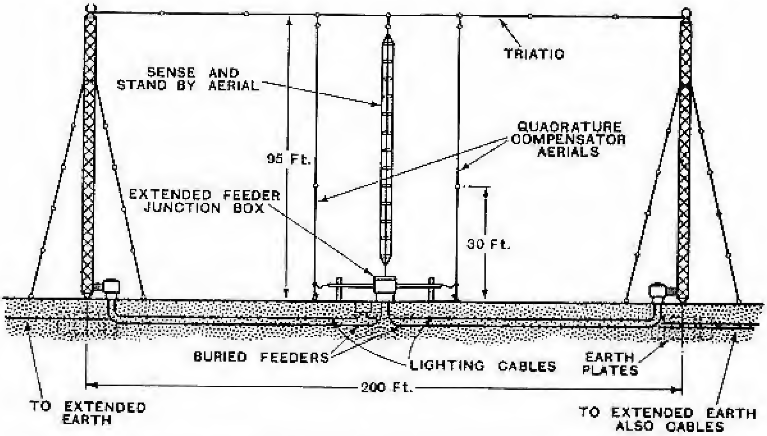

TRIATIC
SENSE AND STAND BY AERIAL
QUADRATURE COMPENSATOR AERIALS
95 Ft.
EXTENDED FEEDER JUNCTION BOX
30 Ft.
BURIED FEEDERS
LIGHTING CABLES
EARTH PLATES
200 Ft.
TO EXTENDED EARTH
TO EXTENDED EARTH ALSO CABLES

Fig. 271.—Shielded " U " Adcock Aerial Layout using Mast Aerials and Extended Feeders.

Test for Screening. From what has been said regarding the low values of field strength that may be encountered when working aircraft at great distances, it is obviously necessary to pay special attention to details of screening. When the installation of the aerial and receiver is completed, a test should be made by tuning in a moderate-strength signal and checking the ratio of the receiver outputs, firstly with the normal arrangement and then with the bases of the aerials earthed.

With the layout just described, used in conjunction with the Marconi D.F.G. 10 Receiver (page 336), this ratio has been measured on a commercial station to be 90 db. or about 30,000 to 1 in voltage. A figure approaching this should always be obtained for high-class performance, though it will depend upon the soil conductivity to a considerable extent and may have to be modified in some cases.

SHIELDED "U" AERIAL WITH EXTENDED FEEDERS

A view of the general layout of the above aerial, when modified for use with extended feeders is shown in Figs. 271 and 272, the principle having been mentioned on page 248. The two quadrature compensating aerials, one for each pair of aerials, are supported strictly vertically from a triatic, and are each approximately 30 feet high in the case of 100-foot mast aerials. These and the 95-foot cage aerial for sense determination and for the removal of residual quadrature effect at the receiving point, are led into a central junction box containing the feeder connections and the necessary screened matching transformers for the spaced and sense aerials. This was shown diagrammatically in Fig. 223.

Feeders. The cable normally used has four pairs, each wire being wrapped with paper string and the pair shielded with copper foil, the whole cable being lead sheathed, served and armoured. The length required for any particular circuit is cut off, sealed and fitted with cable heads by the manufacturers to avoid the possibility of damage on the site, but is tested for insulation, phase rotation and attenuation, before use, in the way mentioned on page 174. If discrepancies are found among the four pairs, the two pairs most closely alike are used for the spaced aerials, one of the remaining ones being for sense and the other spare.

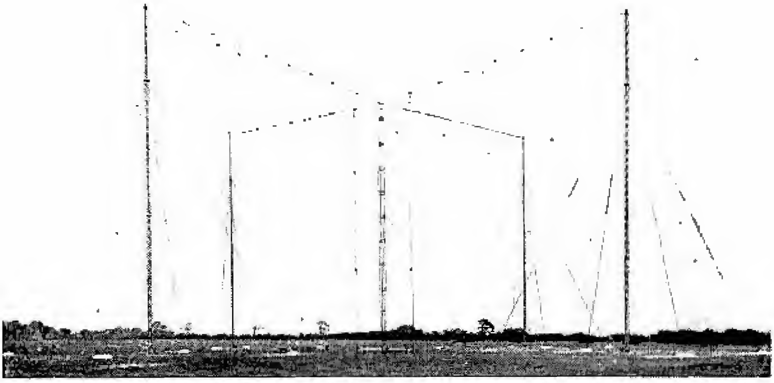


Fig. 272.—View of Aerial System of Fig. 271 (Marconi Co.).

It is interesting to note the excellence of the cables in this respect, discrepancies in attenuation being generally negligible and cross talk between pairs—which is equivalent in this case to mutual inductance between the pairs of aerials—is of the order of minus 80 to 100 db. (10^{-4} to 10^{-5} voltage ratio). Reference (3717) gives details of feeder tests and losses.

Insulation Resistance. The insulation of the complete aerial and feeder installation should exceed 2 megohms. Errors of ±1° are to be expected if the insulation resistance falls to 250,000 Ohms and of ±5° for resistances of, say, 30,000 Ohms.

Earth System. An extended earth system is used to a radius of 250 yards.

Adjustment of Quadrature Compensating Aerials. For this operation it is necessary to have an assistant at the distant receiver and to be able to listen to signals at the aerial junction box, in addition. This may be done by using the spare cable pair as extension telephone leads, and communication can be carried on by using one ear-piece for reception and speaking into the other.

Having disconnected the local zero sharpening circuit at the receiver and tuned in a station, preferably a telephone carrier, in line with the aerials to be adjusted—say the E.-W. pair—the search coil is set to the minimum signal position. With the search coil now at maximum coupling with the N.-S. aerials, the quadrature compensating aerial of the N.-S. aerials is adjusted for the sharpest minimum by means of the variable mutual inductance in the junction box. Next the process is repeated for the N.-S. aerials and both are again checked.

If a transmitter is chosen that is in a direction intermediate between the planes of the aerials, a sharp minimum can be obtained by an incorrect adjustment that will not hold for other directions. If there is difficulty in finding suitable transmitters, the adjustment may be made when the calibration is done, but in such a case any local transmitter must be used at a distance of at least five wave lengths. (3717).

THE TRANSMISSION LINE ADCOCK AERIAL LAYOUT

The method of conveying the signal from spaced Adcock aerials to the receiving point by twin wire transmission lines has been described on page 247, and is shown in principle in Fig. 222. There follows now a description of a commercial installation of this system.

Standard Telephones and Cables, Ltd. Type R.3. Adcock D.F. In this case the receiving building is normally situated 50 to 100 yards from the centre of the aerials and this distance may be increased to rather more than 500 yards at the expense of a small reduction in sensitivity. For great distances, the use of separate lines for each aerial leads to difficulties in maintaining equality of output amplitudes and phases at the receiving point, and the e.m.f.'s of the opposite pairs of spaced aerials are combined centrally, as in the Buried "U" Adcock, the complete system then using three, instead of five, lines.

Aerials. The normal aerial layout consists of four vertical conductors at the corners of a square of 212 feet side, and a fifth at the centre of the square for sense and zero sharpening. The stranded wire aerials are supported by wooden poles as shown in Fig. 273, or by wooden lattice towers. Alternatively, tubular steel masts are used with wire stays, suitably broken by insulators.

Each aerial feeds its transmission line through a shielded impedance-matching transformer with balancing network, as already described on page 247.

The arrangement is shown diagrammatically in Fig. 274, and it may be noted that the lead sheath and armouring of the cables are not connected to the cast-iron container, nor to any earth plate, although the armouring is in contact with the earth throughout its run. Concentrated earth connection is found to increase the unwanted pick-up of the feeder system, and this may be contrasted with what has been said on pages 235 and 311 regarding the effects of earthing co-axial feeders in the buried "U" system. See also Fig. 287.

Lining up the Aerials. For the lining up of the aerials a portable oscillator is used with a vertical aerial. When adjusting, say, the N.-S. pair, the oscillator is set along an extension of a line through the E.-W. aerials as at O_1 in Fig. 275, and hence exactly equidistant from N. and S. The outputs of these aerials are now balanced accurately for phase and to within about 0.1% for amplitude. Mis-balance of these opposite pairs results in quadrature effect (page 236).

The N. and W. or S. and E. aerials are similarly checked by setting the oscillator at O_2 and in this case the outputs are lined up to within 1% to 2%. A discrepancy in the balance of one pair against the other pair will be a measure of the error to be expected in the bearing of a signal incident midway between the planes of the spaced pairs, say N.-E., S.-W., etc.

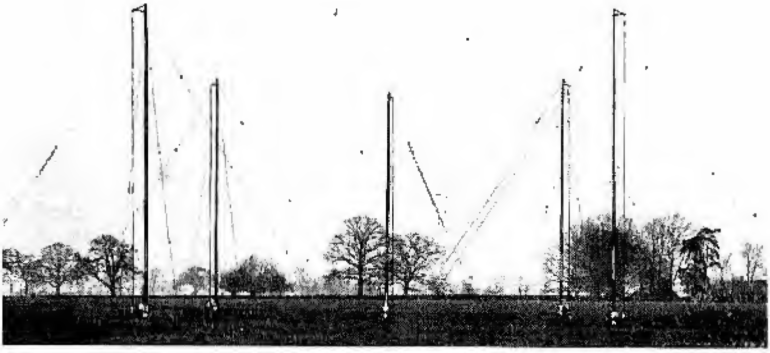


Fig. 273.—View of Wooden Masts and Wire Aerial System of "Transmission Line" Adcock Aerial (Standard Telephones and Cables).

The sense aerial is also approximately balanced against the others, using an oscillator position on the line through O_3, and all the adjustments should hold for some months, although a check is included in routine maintenance. (3802).

Receiving Apparatus. The radiogoniometer and receiver, together with the performance of the equipment, are described on page 342.

ADJUSTMENT OF APPARATUS USED WITH B-T AERIALS

The following types of circuit are now to be considered with respect to the apparatus inside the receiving room, and the adjustment of the circuit;

Tuned Aerial Closed Loop B-T.

Aperiodic Aerial Closed Loop B-T. and Adcock.

Twin- or Multi-Channel Working.

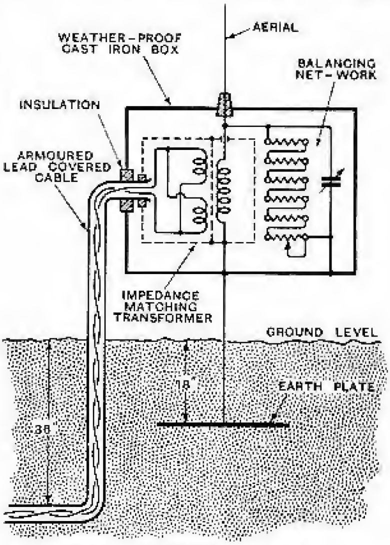

AERIAL
WEATHER-PROOF CAST IRON BOX
BALANCING NET-WORK
INSULATION
ARMOURED LEAD COVERED CABLE
IMPEDANCE MATCHING TRANSFORMER
GROUND LEVEL
18"
EARTH PLATE
36"

Fig. 274.—Matching Transformer and Balancing Network at Base of Aerials of Fig. 273 (Standard Telephones and Cables).

TUNED B-T CIRCUIT

The tuned B-T system is now obsolete for commercial purposes and its principal interest centres in the contrast between the simplicity of the modern aperiodic circuit and the comparatively complex adjustment and the precautions necessary with the tuned system.

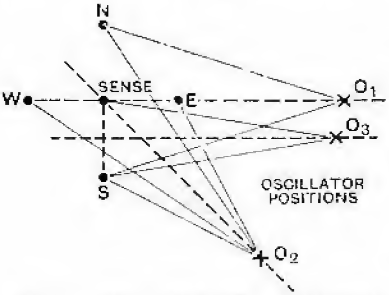


Fig. 275.—Portable Oscillator Positions for Lining-up T.L. Aerial System.

It is worth keeping on record, not only because it was an important stage in the development of practical direction finding, but because it is occasionally useful in experimental work and its technique is so different from that of the aperiodic aerials that a knowledge of the latter alone would be of little help.

At the time when the tuned system was in use, up to about 1917, it was almost always made up as a bench set, employing separate units, and is so described below; but, subject to reasonable precautions, which will become apparent, it could be built up into a modern screened unit receiver if desired. The circuit is shown in Fig. 133, and a bench layout in Fig. 276.

Precautions in Wiring. On entering the receiving room, the aerials are usually connected to a lightning arrester or an aerial earthing switch, or both. As the tuned loop is not connected to earth, the arrester serves to safeguard the radiogoniometer and receiver from the effect of " fizzly " (page 310) and other phenomena of this sort. Neither of them would afford any appreciable protection if the aerial were actually hit by the main stroke of a lightning discharge.

The tuning buzzer,* the use of which has been described in Chapter 5, and the aerial disconnecting switches follow, the latter being required during the process of tuning and balancing. From the lead-in to the radiogoniometer the wiring should be supported on insulators spaced at short intervals and the greatest care taken that the wires of the aerials are spaced at least two or three inches apart and symmetrically arranged so that mutual inductance between the pairs of leads is as small as possible. It may be found necessary to make provision for a small amount of mutual inductance between the aerials to counteract an equal and opposite amount elsewhere in the aerial circuit, but this need not be anticipated and the whole of the wiring should be arranged rigidly.

It is very inadvisable, when connecting up the apparatus of a tuned aerial circuit, to run any wires through the bench, cleating them along underneath and then bringing them out on to the surface again alongside the instrument to which they are to be connected. The reason for these precautions is that dielectric losses in the bench, walls, etc., may cause unequal damping in the aerials with consequent production of bad minima, and furthermore the capacity between the aerial leads and the bench is quite enough, particularly on wave lengths below 300 m., to give capacity coupling between the aerials. On longer wave lengths the effects are not so marked and the same precautions need not be taken, but the point is worth bearing in mind when using tuned aerials.

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* See footnote on page 141.

The Radiogoniometer. The radiogoniometer should be fixed in such a position that it can be easily manipulated without the user's arm constantly moving near to the aerial leads. The orientation of the radiogoniometer and the angle at which it is tilted have a negligible effect.

Aerial Tuning Condensers. The variable tuning condensers, one of which has a vernier condenser in parallel, must be of high quality with good electrical connection between the vanes and the spindle or frame supporting them. A heavy die-cast type is advisable and if inferior ones are used it may be found that accurate balancing is impossible. The leads from the radiogoniometer to the aerial condensers form part of the aerial circuit, and the same care should be taken here to avoid mutual induction between them. For this reason the radiogoniometer and the condensers must be fixed to the bench or trouble is almost bound to arise from the above cause.

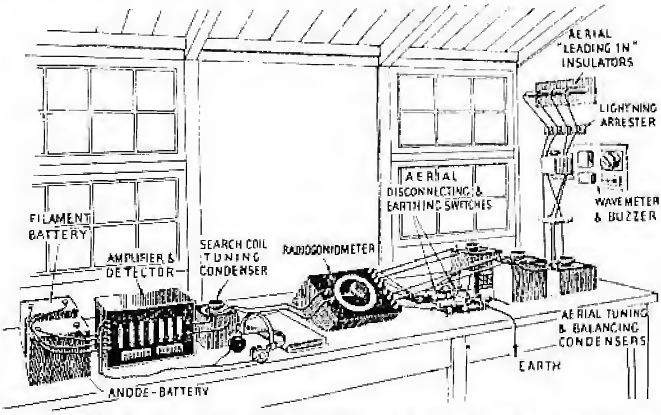

AERIAL "LEADING IN" INSULATORS
LIGHTNING ARRESTER
AERIAL DISCONNECTING & EARTHING SWITCHES
WAVEMETER & BUZZER
FILAMENT BATTERY
AMPLIFIER & DETECTOR
SEARCH COIL TUNING CONDENSER
RADIOGONIOMETER
AERIAL TUNING & BALANCING CONDENSERS
EARTH
ANODE-BATTERY

Fig. 276.—Illustration from First Edition of this Book showing Layout of Tuned B-T Apparatus in Use up to 1917.

Earth Connection. It will usually be found advantageous to earth the common connection of the filament and anode batteries, and also the screens of any screened units. In an unscreened or partially screened layout, it is sometimes found better not to earth the batteries. The point may be easily settled by trial and if an improvement is found by not earthing, it will often be found an additional advantage to insulate them, since they may be forming a leaky capacity connection to earth.

C.W. Reception. The chief precaution to be observed when using a separate heterodyne for C.W. reception is to ensure that it is not coupled with the radiogoniometer, for, in this case, trouble will ensue owing to the oscillator signals having a definite direction of their own and producing another pair of minima.

Tuning and Balancing. During the tuning and balancing the magnification of the amplifier should be reduced until only medium strength signals are heard. If this is not done it may be found difficult to balance owing to the noise caused by direct induction in the D.F. search coil from the exciter circuit.

Adjust the aerial tuning buzzer to the required wave length and rotate the moving coil of the wavemeter to some position intermediate between the planes of the two aerial turns. Disconnect one aerial and tune everything up to buzzer wave length, then disconnect the tuned aerial and connect the other, again tuning to buzzer wave length and for this purpose it should not be necessary to alter anything except the aerial condenser.

In doing the above tuning the coupling of the radiogoniometer should be kept loose, that is to say, the search coil should be nearly at right angles to the field coil in circuit. When both aerials are tuned, close both the aerial switches and turn the pointer to the position of minimum signals. In the case of a D.F. wavemeter which has a rotating coupling coil, the position of this minimum will depend upon the position of the coupling coil relative to the aerial turns, but should always be adjusted, as stated above, to some position intermediate between the two. Now adjust the vernier aerial tuning condenser until the best minimum is obtained, slightly varying the position of the pointer of the radiogoniometer during the process if necessary.

For the reception of modulated signals—and this was more essential in the days when spark transmissions were still in common use—the resistance and damping of each aerial loop must be identical. With different sizes of loop which may arise during calibration, the L/C ratio will be changed, and hence the decrement, whilst different types of aerial wire, poor electrical connections in the aerial circuit, dielectric losses when on wave lengths below, say, 300 m., will have the same effect.

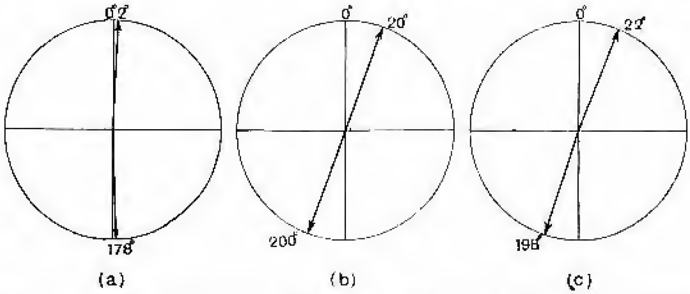


Fig. 277.—(a) Two Degrees of Vertical. (b) Twenty Degrees of Pointer Rotation. (c) Combination of (a) and (b).

As a result of this the currents in the two loops will have different decay coefficients and a balance becomes as impossible to attain as if the currents were relatively mis-phased.

It has been assumed that the aerial system and circuit are free from vertical and direct pick-up, and that the radiogoniometer is in correct adjustment. These points can be confirmed in the following way.

Test for Antenna Effect and Direct Pick-Up. For this purpose strong signals are required approximately in line with each aerial loop in turn and if actual stations are not available a wavemeter energized by a buzzer circuit should be used near to the loop under test.

With the E.-W. loop disconnected, listen to signals on the N.-S. loop with the amplifier gain at a high figure. If two sharply defined points of zero signal strength are found at 0° and 180° on the scale of the radiogoniometer, neither of the above effects is present. If the minima are not diametrically opposite, as in Fig. 277 (*a*), or if the minima are indefinite or if both these effects are observed, then either antenna effect or direct pick-up is taking place. If the effect is due to antenna effect, there will be silence in the telephones when the loop under test is also disconnected, but if signals are still heard in this case they must be due to pick-up on the wiring or the receiver components and the remedy is obvious, whilst the remedies for antenna effect have been mentioned on pages 85 to 88.

If the minima are diametrically opposed but rotated through an angle from the 0°–180° direction, this is due to the pointer of the radiogoniometer being displaced on the spindle, and, if the aerials have been accurately laid out, the pointer should be moved to, and secured in, the correct position. This is shown in Fig. 277 (*b*) whilst 277 (*c*) shows a combination of antenna effect or pick-up combined with a rotation of the pointer.

Quadrature Effect. The possibility of quadrature e.m.f. must be kept in mind but troubles due to re-radiation to a degree capable of causing indefinite minima on a tuned B-T station are not to be anticipated if the site has been well selected. The effect is more common in ship installations and is dealt with on page 406.

Test for Mutual Inductance Between Aerials. The symptom of mutual inductance or capacity between the aerials has been seen on page 142 to be an indefinite minimum which may possibly be displaced and the following test should always be made as soon as the receiving apparatus is installed to ensure that the aerial system is not at fault.

The energized wave meter, mentioned above, must be placed under one of the aerials " A," a position near the aerial anchor probably being found suitable, depending upon the degree of amplification used. The whole of the apparatus is then tuned up to buzzer wave length.

Now disconnect aerial " A " and adjust the position of the exciter coil until no signals are heard in the telephones, indicating that the exciter coil and the other aerial " B " are not coupled.

Leaving the exciter circuit in the same position, disconnect aerial " B " and connect aerial " A " and again obtain silence in the telephones, but this time by adjusting the position of the search coil, indicating that the aerial " A " and the search coil are not coupled.

Now connect both aerials and if buzzer signals are heard there is mutual induction or else capacity coupling between the frames or some part of the aerial circuit. The reason for this is as follows: Since the search coil is in a position in which it is unable to receive any signals from aerial " A," any buzzer signals must be received via the aerial " B." This aerial however, is not coupled with the buzzer coil so that it follows that signals must be received on aerial " A," communicated to aerial " B " by means of the coupling between the frames and thence to the search coil circuit.

If the coupling happens to be only small, it can probably be corrected by altering slightly the relative positions of the leads between the lead-in insulator and the radiogoniometer, so as to introduce an equal and opposite inductive coupling. If it be found that this balance is not maintained on changing the wave length, it may mean that the coupling was a capacity one and a balance of the latter type must be arranged. The necessity for this should not arise unless the aerials are very close to the receiving building, the aerial leads have been carelessly run, or unless the apparatus and leads have been enclosed in screening cases and asymmetry has been introduced. Should the signals from the buzzer be very loud when the two aerials are connected, the trouble is more likely due to errors in the laying out of the aerials and their directions should be checked to make sure that the two frames are exactly at right angles.

To show the sensitiveness of the test, it may be mentioned that when using high magnification and tuned aerials, the effects of the coupling of taut aerials, due to their swaying in a light breeze, can be easily detected.

THE APERIODIC B-T CIRCUIT

Fig. 283, and those following, show a modern radiogoniometer and receiver for use with aperiodic loop or Adcock aerials, and the circuit diagrams show the care that is necessary to obtain symmetry of the input circuit to the amplifier in order to reduce antenna effect. Valve amplification of the auxiliary aerial effect is also used, with precautions regarding cross modulation, whilst the whole design is split up into well-screened compartments. This screening is carried to extreme lengths in the apparatus for twin-channel working which is described later.

As indicating more clearly, however, the contrast between the handling of the tuned loop and the aperiodic system, the simplest form of aperiodic circuit of Fig. 134 is described as follows. It may be mentioned that all commercial D.F. apparatus is equipped for sense determination so that the simple aperiodic circuit is rarely encountered and these remarks may be taken as introductory to the next section, dealing with the heart-shape circuit.

The salient points of the aperiodic circuit are as follows :

(1) There is less trouble due to the coupling between the aerial loops owing to the fact that they are not in resonance with the signal frequency at the minimum point (page 120), and hence a comparatively tight coupling between them is required in order to influence the minimum appreciably.

> (2) Additional precautions are necessary for screening the apparatus from direct pick-up, because signals are weaker than with tuned aerials, and the high amplification that is thereby required results in the pick-up of the radiogoniometer and input circuit coils being emphasised.
>
> (3) Antenna effect is also more pronounced for the above reason.

To continue the comparison between the tuned and aperiodic systems, the aerial tuning wave meter and buzzer are omitted in the latter case, since there is no balancing to be done. The lightning arrester is no longer required, the loops being permanently earthed at the mid-points of the field coils, and hence the trouble due to the discharge of " fizzly " is largely removed. Aerial-disconnecting switches are not necessary and, although they might be convenient for checking the position of the radiogoniometer pointer relative to the loop directions, and also for rapid checks for the presence of vertical, they are always a potential source of error due to bad contacts. They are therefore not usually fitted.

Whilst it is advisable to keep the resistance of each loop the same, and also as low as possible, the addition of several ohms in series with the loops is often found to make very little difference in signal strength, even at signal maximum. The reason for this is that the loop is being tuned through a transformer, namely the radiogoniometer, which has a coupling coefficient of, say, 70%. Since the transformer is not a perfect one, the loop circuit, even when tuned, will have a reactance vector in addition to the small residual resistance vector inherent in any circuit and so it becomes possible to increase this resistance vector considerably with little effect upon the impedance.

When a shielded transformer is added between the tuning condenser and radiogoniometer, the net coupling coefficient is still further reduced and the loop becomes more reactive and still less sensitive to added resistance.

Since the aerials are untuned at the point of minimum signal strength, there will not be any great transfer of energy from one to the other even if coupling exists to an extent which would produce very indefinite minima in the tuned aerial system. The leads from the aerial to the radiogoniometer need, therefore, not be supported with the same care and there is very little chance of introducing errors even if the aerial leads be made of twisted flexible wire and allowed to run haphazard. In the same way, mutual induction between the aperiodic aerial loops has very much less effect upon the performance of the circuit than in the case of tuned aerials.

Sharpness of Minima with Aperiodic Aerial Circuit. For the reasons mentioned in the previous two paragraphs, signal strength with the aperiodic aerial system is far less than with tuned aerials and more amplification is normally used. As a result of this, unless special precautions are taken, there is appreciably more direct reception on the coils of the apparatus with consequent blunt and indefinite minima. By taking extreme care with the screening of the various parts of the circuit it has, however, been demonstrated that the crispness of the minima and the sensitiveness of the aperiodic aerial D.F. may be made quite equal to that of the tuned aerial circuit.

Earthing of Receiving Apparatus. Earth connection is made to the mid-point of the radiogoniometer field coils, to the screen of the search coil if fitted, or to the screen of the transformer ; also to the common negative of the batteries and to the screening case or cases of the complete apparatus.

Tuning. The adjustment of the circuit to the desired frequency is now as straightforward as a receiver and open aerial, since the search coil condenser tunes both loops and there is, of course, no balancing to be done.

Slight mis-tuning of the circuit will not, in general, produce errors in bearings except that, by weakening the frame signal strength, the proportional effect of any antenna effect that is present is increased.

Checking for Antenna Effect and Direct Pick-Up. The same procedure should be carried out as for tuned aerials, but, as mentioned above, both these effects will be more noticeable and whether closed loops or Adcock aerials are being used it is advisable to reduce antenna effect and pick-up to the smallest amount possible, and not to rely more than is necessary upon zero sharpening circuit devices.

See " Test for Screening " on page 313 with regard to the Adcock layout.

Checking for Mutual Inductance. Since aperiodic loop aerials are less sensitive to the ill effects of mutual inductance than are tuned aerials, it is not necessary or possible to carry out the test for mutual as described on page 322. If for any reason it is desired to make this check, the aerials may be temporarily tuned by connecting condensers in parallel with the field coils.

THE APERIODIC HEART-SHAPE CIRCUIT

The simple aperiodic circuit is now extended to the more usual arrangement in which the true cardioid—or at least a unilateral diagram—can be obtained for sense determination.

In Fig. 138, the theoretical diagram of this circuit was given, and it was seen, on page 119, that the heart-shape diagram of reception could be obtained by the use of an auxiliary aerial which has an e.m.f. leading by almost 90° on the loop e.m.f.

A resistance in series with the vertical aerial lead performed the double function of stabilising the phasing of the circuit and also adjusting the amplitude of the current in the vertical aerial.

Aside from the use of the heart-shape diagram of reception for the determination of sense, it may also be used at a receiving station for eliminating jamming. When used for this purpose it is preferable to maintain a complete zero of signals at the minimum point of the polar diagram and some instructions on the operation of the circuit, shown in Fig. 278, are given below.

The radiogoniometer used is now tightly coupled and may have either a screened search coil, as in the design shown in Fig. 145, or a screened transformer may be used.

The radiogoniometer is also fitted with two pointers, one at right angles to the other for use in sense determination.

The open aerial circuit contains the resistance R which should be reasonably non-inductive, and a tuning inductance L_1, the latter being coupled direct to the search coil circuit L_2, S, L_3, C_1. In a more elaborate arrangment of the circuit, when very sharply defined cardioid minima are required over a wide wave length range, L_1 may be split up into a separate coupling coil and tuning inductance. In the case of a directional receiver, there may also be a variable condenser C_3 (shown dotted) for final adjustment of open aerial phasing, but such refinements are unnecessary in a D.F.

Adjustment. On the assumption that an open aerial tuning condenser is used, it may be either in series or parallel with the aerial. If the condenser is in series with L_1 and R the reactances will in general be so large that a cardioid balance can only be obtained with very high values of R, necessitating an unduly large open aerial. The parallel condenser circuit is therefore generally used, if any.

In adjusting the apparatus, first disconnect the open aerial circuit and tune the intermediate or search coil circuit so as to get satisfactory figure eight reception with sharp minima.

Next connect up and make preliminary tuning of the open aerial circuit C_3 L_1, having rotated the search coil to a position of figure eight minimum. Adjust the coupling of L_1 L_2 to some moderate value, and having obtained maximum signals by varying L_1 or C_3, indicating approximate resonance in this circuit, L_1 or C_3 should be reduced slightly from resonance value.

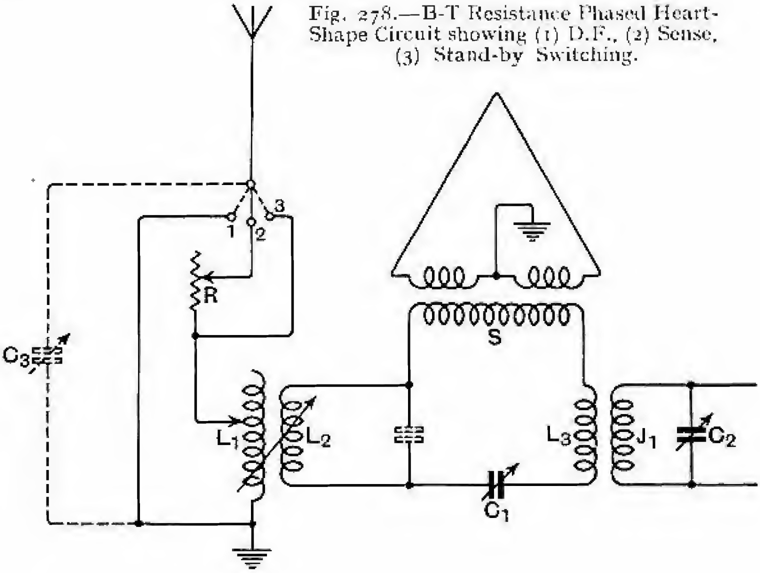


Fig. 278.—B-T Resistance Phased Heart-Shape Circuit showing (1) D.F., (2) Sense, (3) Stand-by Switching.

The reason for this has been explained on page 120 and holds good for practically all closed loop installations in which the radiogoniometer is connected direct to the aerials. When long cables are used, that form part of the aerial oscillatory circuit (as distinct from transmission lines), and the receiver is being used near to the bottom of its range of wave length, it may happen that the current in the field coil is leading, instead of lagging, at the point of cardioid minimum, and this condition will require a slight increase of L_1 or C_3 to obtain a balance. This applies also to the Adcock aerials which have leading currents at the signal minimum.

It is unlikely that the correct adjustment of the whole circuit will be achieved at the first trial and on rotating the search coil, the polar curve of signal strength will probably take the form of that shown either in Fig. 54 (*d*) or Fig. 54 (*a*) with indefinite minima. The former shows the effect of too great an e.m.f., in the intermediate circuit, due to the open aerial and the latter the reverse condition, and it must be remembered that this e.m.f. may be varied either by the resistance R or the coupling L_1 L_2. The resistance R, however, is also in use for varying the phase condition of the open aerial circuit and will have a definite best value, depending on the amount by which this circuit was detuned by the slight alteration of the inductance L_1 from the resonance value.

The ensuing balancing operation, to get the single crisp minimum, will therefore be a compromise between the values of R and the coupling L_1 L_2. Having obtained one or the other of the polar curves first vary the coupling to give the best minimum and then alter R slightly. If the minimum is still indefinite, the phasing of the vertical aerial circuit is probably incorrect and L_1 or C_3 should be slightly altered and the balancing process repeated until a complete zero of signals is obtained.

When it is found possible to get a true heart-shape balance on continuous wave signals but not on atmospherics or telephony stations, the cause will usually be found in the incorrect amount of resistance in the open aerial, and this is discussed below.

During long spells of dry weather, or in places where there is difficulty in making a good earth connection, it may be found that the amount of resistance required in the open aerial is variable and smaller than the normal value ; also that there is difficulty in maintaining the true zero of signal strength. This may usually be traced to a high-resistance earth connection.

Open Aerial Phasing. The open aerial circuit has been redrawn in Fig. 279, together with a vector diagram in Fig. 280, to illustrate in greater detail the operation of the correct phase adjustment of the open aerial. V_P is here taken as the voltage across the parallel tuning circuit and V_A as the voltage across the remainder of the mainly capacitative aerial circuit represented by C_A.

Starting with OV_P in Fig. 280, the current in C is shown leading by 90° on this voltage and the current I_{RL} lagging by an angle θ where $\cot \theta = \frac{R}{2\pi n L}$. The resultant I_{CA} is the open aerial current which leads 90° on V_A. The open aerial e.m.f. O*e* is the vector sum of OV_P and OV_A and the balancing process consists in obtaining the correct amplitude of I_{RL}, the correct angle of lead ϕ on the open aerial e.m.f. and the correct value of aerial damping.

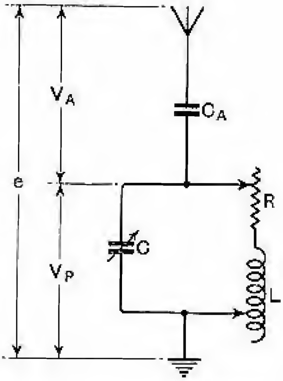


Fig. 279.—Resistance-Phased Open Aerial Circuit.

Variation of Phasing Resistance with Received Frequency. When an installation covers a wide range of wave lengths, it will be noticed that the phasing resistance has to be increased in value, in order to obtain a satisfactory cardioid balance on any telegraph or modulated transmitter, as the wave length is increased. To appreciate the reason for this, it should be noted that the balance has to be maintained, not for a spot frequency, but for a band of frequencies and for this purpose aerial damping is required. The width of the frequency band is determined by the keying or modulation side bands in the case of a telegraph station, by the speech bands of telephony, and is widest of all in the case of atmospherics.

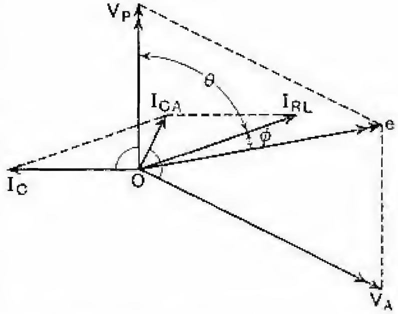


Fig. 280.—Vector Diagram for Circuit of Fig. 279.

The effect of a change of applied frequency to the aerial is to produce a change both in the amplitude and phase of the current, but it is the latter that will normally be the first factor in destroying the balance of the open and loop aerials, unless corrected by additional damping.

The phase shift is governed by the damping d, which is proportional to R/nL. Since, however, n^2 is proportional to $1/L$, d may be written proportional to Rn, or R/λ.

For a given value of damping, R is thus inversely proportional to frequency and directly proportional to wave length.

It has been said above that the frequency band is governed by the transmitter, but it is, of course, limited by the width of frequency band that the receiver is capable of handling, and, in cases where a variable band filter is used, it is noticed at once that the cardioid balance can be obtained with less open aerial resistance when a narrow band of frequencies is being received.

Detuning Due to Excessive Open Aerial Resistance. The expression for the frequency of a circuit such as that of Fig. 281, is given by :—

$$n = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

in which $\frac{R^2}{4L^2}$ is negligible compared to $\frac{1}{LC}$ except when large amounts of extra damping R have been added.

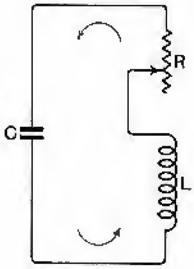


Fig. 281.—Open Aerial "Parallel Condenser" Circuit.

As the frequency of the circuit is reduced (wave length increased), the factor $\frac{1}{LC}$ will become progressively smaller whilst, for a given amount of damping, $\frac{R^2}{4L^2}$ will increase, for the reasons mentioned above. As a result, if an attempt be made to control the phase shift to within too fine limits at low frequencies, a condition is reached for which the resistance factor affects the tuning to such an extent that a considerable retune of the open aerial is required on switching over from the 'stand-by' to the cardioid circuit.

It is therefore usual to compromise and not to attempt to obtain too restricted a phase shift on medium or long waves as, apart from mis-phasing, the necessary resistance may reduce the amplitude of the open aerial current to a point when there is difficulty in obtaining a cardioid balance on this account.

A larger aerial, with increased capacity, will always provide a solution as this reduces the inductance necessary for resonance and, since damping is proportional to $\frac{R}{L}$, a reduction in L will lead to less resistance being required for a given phase shift control.

Tuned Open Aerials. A point to be remembered in connection with the aperiodic heart-shape circuit is that the balance may be ruined by an open aerial in the vicinity which is tuned to the same wave length as that being received on the aperiodic system. The low damped tuned aerial will radiate during the passage of the wave and will have the effect of increasing greatly the apparent open aerial effect of the aperiodic heart-shape balance. On D.F. stations, therefore, where a cardioid circuit is used for the elimination of interference when working traffic, it is necessary that any open aerial reception, that is being done simultaneously at the station, should employ aperiodic aerials.

D.F. — Sense — Stand-by. When using the aperiodic heart-shape circuit, some form of switching device should be incorporated in order that the polar diagram of reception may be changed rapidly from the figure eight to the heart-shape; and provision may also be made for non-directional reception for the purpose of standing by for signals. In Fig. 278, such a simple switching arrangement has been shown.

D.F. With the switch in position (1), the result is a simple aperiodic aerial system with a loose-coupled receiver, for it will be seen that the phasing resistance R and the vertical aerial coil L_1 are out of circuit.

Sense. With the switch in position (2) the open aerial is connected to earth through the phasing resistance R and the coil L_1, which gives the condition for heart-shape reception.

Stand-by. In position (3) the circuit is seen to be the same as for sense, except that the phasing resistance is out of circuit and, as a result, the current in L_1 increases several-fold, with consequent increase in induced e.m.f. in L_2 and the intermediate circuit. This swamps the effect of the loop reception and gives practically equal strength of signals from all directions.

In accurate D.F. work, as distinct from directional reception, the switching arrangements are more complicated because provision may have to be made, when using the figure eight reception, for the coil L_1 to be totally disconnected. If this coil be connected to earth at one end, then, owing to the comparatively tight coupling between L_1 and L_2 there will be capacity coupling to earth from one side of the search coil with consequent production of antenna effect.

Stand-by Using Quadrature Phase Relationship. In some cases the open aerial is not large enough for its e.m.f. to swamp that of the frame, and a distorted cardioid results from any attempt to get omni-directional reception by this means. This can be avoided by ensuring that there is quadrature phase relationship between the frame and open aerial, which results in a rotating field and no possibility of phase opposition. This has been done in the circuits of Figs. 285 and 366.

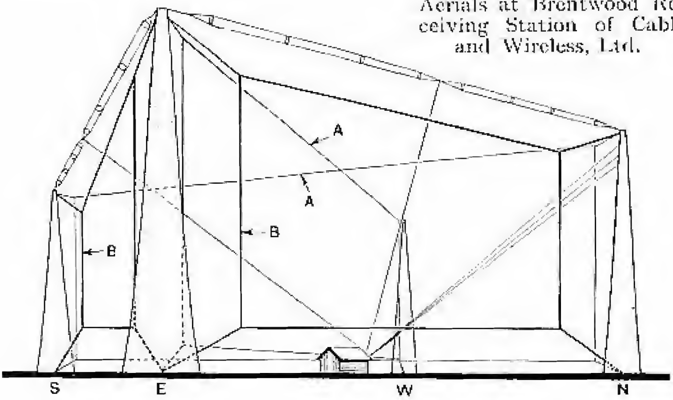


Fig. 282.—Rigging of B-T Aerials at Brentwood Receiving Station of Cable and Wireless, Ltd.

THE MULTI-CHANNEL MARCONI B-T (OR ADCOCK) SYSTEM

This multi-channel directive system has been used in a number of commercial receiving stations for as many as eight channels on one pair of B-T loops, and also for twin channel direction finding on Adcock aerials. A description is given below of the method of adjustment of the former installation, as being somewhat more comprehensive, but the principles apply equally well to the twin channel B-T or Adcock D.F.

Marconi Eight Channel B-T System. The aerial system does not differ from the ordinary B-T aerial except that in the case of a directional receiving station it is usual to make the loops rather larger than would be used for D.F. work, and provision must be made for the requisite number of open aerials for the production of the cardioid diagrams on the receivers connected to the loops.

Fig. 282 is a sketch of the long wave B-T aerials and masts at the Brentwood receiving station of Cable and Wireless Ltd. The four 200-foot towers are at the corners of a square of 450-foot side and two complete B-T systems are employed.

Two loops AA are supported along the diagonals of the square, each being about 600 feet by 180 feet and having an inductance of 900 μhy. Connected to this pair of loops are eight receivers, each having a wave range of 5,000 to 20,000 m.

The second pair of loops BB are suspended between the N.-E. and E.-S. towers, and these, although at right angles, do not intersect and hence have considerable mutual inductance, but it is an interesting example of the adaptability of the aperiodic aerial system that fair cosine minima and perfect cardioid minima can be obtained. Eight more receivers, each with a wave range of 2,000 to 5,000 m. are used on these loops.

Of the sixteen open aerials required for cardioid reception, some are of the "cage" type, the larger capacity of which enables a satisfactory cardioid to be maintained on wave lengths above 10,000 m., and the remainder are single wires attached to various points on the towers, and have not all been drawn in. The number of open aerials rigged does not appear to matter so long as they are all aperiodic. Three single wires, for instance, are slung from the top of one of the towers, being only a foot or so apart at their open ends, whilst another set of eight open aerials, not shown, are brought down and secured at two-foot intervals along a low triatic for convenience of leading in to the building. None of these aerials cause mutual interference, but if a single tuned open aerial be used at the station, the cardioid balances are immediately upset, due to re-radiation.

Aerial Bus-Bars. The active and dummy aerial connections between the receivers may be run in any convenient manner, preferably so as to have minimum mutual action on one another. To have each set of connections in cage formation (similar to Fig. 267 but in miniature), the spacers rigidly supported and the active and dummy connections in separate screened chases, is probably ideal, but little trouble need be anticipated if twisted flexible pairs are used, separated by a few inches.

Double Radiogoniometer. If the radiogoniometer be of the double pattern, the first essential is to make sure that the search coils are properly aligned. By this is meant that when the active search coil has minimum coupling with its N.-S. field coil, the dummy search coil must also have minimum coupling with its N.-S. field coil. This point can easily be checked with an exciter circuit and telephones.

Other points worth checking are that all the field coil windings are identical and also that, in the case of a number of receivers, all the field coils are wired up in the same way to the terminal blocks and that none of the coils has been wound left-handed if the remainder are right-hand wound. These faults are unusual, but are worth anticipating and may save irritating delay later. If octantal error is present, it should be the same in each radiogoniometer.

Single Radiogoniometer with Split Field Coils. If the radiogoniometer is of the type shown in Fig. 168 then there is no possibility of trouble due to the search coils not being in alignment since one coil is common to both sets of field coils. The other precautions regarding the winding of the field coils are less necessary since the instrument is very little more complicated than the normal radiogoniometer.

A point worth bearing in mind is that if the coupling be made too tight there will be a certain amount of mistuning of the search coil circuit, when it is rotated, owing to the asymmetry of the field coils (Fig. 169). The result of this asymmetry is to upset the cosine law of the radiogoniometer, although it is, of course, perfectly suitable for directional reception as distinct from D.F.

Dummy Aerials. The dummy aerials are composed of solenoids on insulating formers and are enclosed in copper screened boxes. The two boxes can be mounted in any convenient position and must be so placed that the coils have no mutual inductance. It is not usually possible to construct the dummy coils to have exactly the correct inductance value unless the electrical constants of the aerial are accurately known beforehand. The windings are, therefore, sometimes made with tappings or in variometer form. If a plain untapped coil be used, the correct position may be found for the tap by making connection to the winding with a pin, which is pushed through the insulation and which generally makes contact with some of the strands. The wire can later be cut back to the correct balance point.

Adjustment of Anti-Coupling. When balancing the aerial circuits, it is an advantage to do so on signals from a transmitter which is close at hand, since the balance point, in this case, can be found more easily. It is also advisable to calculate the inductance required for the dummy aerial coils, and to adjust these temporarily; that is to say, by a tapping or by the use of a pin as mentioned above. The formula for finding the inductance is given on page 179.

Balancing should be done in the first place on one aerial loop at a time, say the N.-S. loop, with the active and dummy N.-S. field coils connected and the E.-W. active and dummy circuit disconnected. The search coil circuits of No. 1 and No. 2 receiver are both tuned to the test signal, care being taken that in each case the search coil is exactly in the position of maximum signals, that is to say, has the maximum coupling with the N.-S. field coil.

This being done, listen to test signals in No. 1 receiver, whilst the search coil of No. 2 receiver is rotated, and observe the effect, if any, upon the signal strength. If the two search coils of each radiogoniometer are properly connected and the dummy aerial coils of the correct inductance, there should be no change in signal strength, whilst, if a search coil or field coil be reversed, or the dummy aerial be of entirely the wrong value, there will be a decrease in signal strength for positions of No. 2 search coil, other than that at which the tuning was done. If the dummy has been set to approximately the correct value beforehand, and the field coil windings carefully checked, the trouble is almost certain to be a reversed search coil.

It will be remembered that the method of anti-coupling, described on page 177, depended upon maintaining complete symmetry in the active and dummy circuits and arranging that any mutual inductance between No. 1 and No. 2 search coil circuits, by way of the active field coils and the loops, was exactly balanced out by an equal and opposite mutual inductance due to the dummy field and aerial coils. If, then, there be no coupling whatever between the search coil circuits of the receivers, the rotation of No. 2 search coil cannot have any effect on No. 1 receiver since its only effect is to reduce the mutual inductance between S_2 and F_2 and also between s_2 and f_2, both to the same extent, the balance being unaffected.

If, on the other hand, a field coil or search coil be reversed, there will be double the mutual inductance between No. 1 and No. 2 search coil circuits that there would be if the dummy were not there. In this case, the rotation of No. 2 search coil, from maximum coupling with the N.-S. field coil to minimum, will reduce the mutual inductance to zero. This large change in mutual will detune the No. 1 search coil, and there will be an appreciable fall in signal strength—signals may disappear altogether—indicating immediately that something is wrong. The remedy for this is obviously to find the reversed coil and to rectify it. It may be found that the balance can be restored by the reversal of any search coil or field coil winding, but it is very important to maintain the symmetry of the system and particularly of the active field coils, or errors in bearings will be introduced. The errors due to cross connection of field coils are mentioned on page 355, and careful labelling of all terminals and leads is advisable.

Having eliminated any wrong connections, a more sensitive test can be applied for the balancing of the dummy aerial coils, in which, instead of listening for a change in maximum signal strength in No. 1 receiver, whilst the search coil of No. 2 is rotated, a zero balance of signals is obtained in No. 1. This may be done by connecting up the open aerial and phasing unit of No. 1 receiver and balancing the open aerial and loop e.m.f.'s in the search coil circuit as is done in the case of the heart-shape balance. Rotation of No. 2 search coil will now provide a critical test of the adjustment of the dummy aerial coil, which should be varied until the zero signal balance is maintained for all positions of No. 2 search coil.

An alternative method of balancing, when a signal generator is available, is to use the generator in the search coil circuit of No. 1 channel and to observe signals in No. 2 receiver. The balancing now becomes equivalent to that of a hybrid circuit, as used in telephone practice, and cross talk balances of 30 to 35 db. are commonly obtained.

The N.-S. circuits can next be disconnected and a similar series of tests carried out for the E.-W. system, after which the whole of the aerial connections may be restored. Each radiogoniometer is then checked to make sure that bearings are in the correct quadrants, and finally a heart-shape balance is obtained on each receiver in turn, and the effect observed of rotating the search coils of the other receivers, when tuned to the same or to slightly different wave lengths.

Although it should always be possible to find a heart-shape adjustment on every receiver, in a multi-channel system of this type, which will give a sharp minimum, it is difficult to get perfect results on plain figure eight reception. The balancing must be exceptionally good to give crisp cosine minima under all conditions, but this is no great loss since the heart-shape is much more frequently used for directional reception of commercial traffic.

EXAMPLES OF COMMERCIAL RECEIVING APPARATUS FOR GROUND STATION D.F. WORK

Below are given examples of commercial apparatus used with B-T and Adcock aerials, with short and long feeders; also an example of medium- and long-wave portable equipment.

MARCONI GROUND STATION D.F. TYPE D.F. G.10

The instrument is shown in Fig. 283 and is primarily designed for aerodrome use with Adcock or B-T loop aerials over a normal range of 800 to 2,000 m. (375 to 150 kc.) with various alternatives.

Receiver. Following the input circuit, which comprises the radiogoniometer and the switching circuit for D.F., Sense and Stand-By and which is described below, are four transformer-coupled tuned R.F. Pentode stages of amplification, V_2 to V_5 in Fig. 285. These have separate tuning controls over the complete range, but with a ganged movement of the "fixed" plates of the condensers over a limited range of about $\pm 10\%$ at any wave length.

A local oscillator V_7 is controlled by a switch for C.W. reception and the detector V_6 is followed by two stages of audio frequency amplification. There is potentiometer control of radio and audio amplification, whilst the output of the first L.F. valve V_8 may be switched through either an aperiodic intervalve transformer for voice frequencies, or through a filter

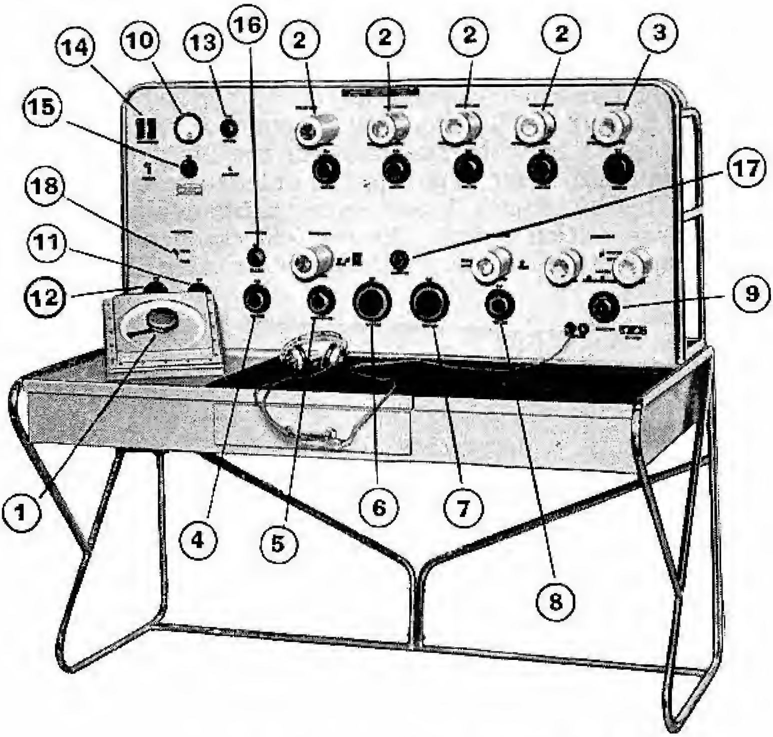


Fig. 283.—Marconi Ground Station D.F. Receiver, Type D.F.G. 10.

1. Radiogoniometer.
2. R.F. Valves with Tuning Condensers below.
3. Detector.
4. Open Aerial Coupling.
5. Search Coil Tuning.
6. Ganged R.F. Tuning for Quick Search
7. R.F. Oscillator Control corresponding to 6.
8. Full Range R.F. Oscillator Control
9. Audio Frequency Gain Control.
10. Supply Volts and Feed Meter.
11. Intermediate Circuit Tuning.
12. Intermediate Circuit Coupling.
13. Filament Voltage Control.
14. Fuses.
15. Meter Selector Switch.
16. Zero Sharpening.
17. R.F. Gain Control.
18. Intermediate Circuit IN-OUT Switch.

circuit tuned to 1,200 c.p.s. By using the latter unit and adjusting the beat tone of the wanted signal to resonance, the background noise may be appreciably reduced during bad interference.

Radiogoniometer. The radiogoniometer has an indirectly lighted scale and is mounted in a brass screening case and sunk in the bench in a position that has been found from experience to be convenient and at the same time leaves access to the ganged tuning, volume, Sense/D.F. and zero sharpening controls. The search coil is screened in the way shown in Fig. 145; the spindle is mounted on ball bearings and the leads from the unit run through a screening tube to the receiver.

Fig. 284 shows a double radiogoniometer of the same pattern, as used for twin-channel working.

Input Circuit. The simplified diagram of connections of Fig. 285 shows how the symmetry of the input circuit has been maintained as far as possible, in order to reduce antenna effect. The D.F., Stand-By and Sense conditions are controlled by a three-position switch, the cardioid being provided by valve amplification. The input to the sense valve V_1 from the open aerial is untuned, being resistance capacity coupled, so that there is a 180° change of phase between the input and output of this valve. The open aerial e.m.f. in the search coil circuit will thus be either in phase with, or in phase opposition to, the spaced aerial e.m.f. in the search coil circuit at cardioid minimum.

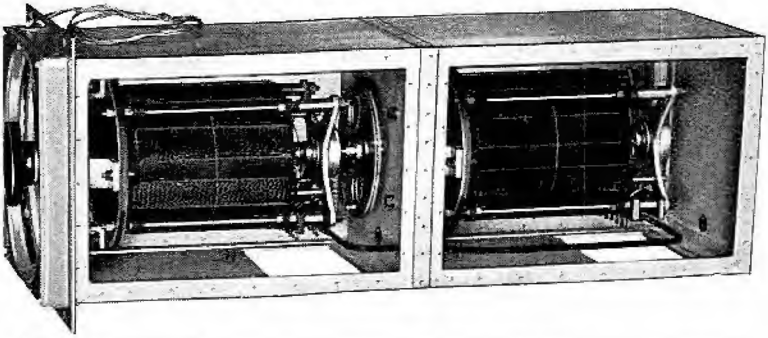


Fig. 284.—Double Radiogoniometer for Twin-Channel D.F. Reception (Marconi Co.).

It must be remembered that the spaced open aerials form a capacitative circuit, and so have a leading current instead of a lagging one as is usually the case with a closed loop (page

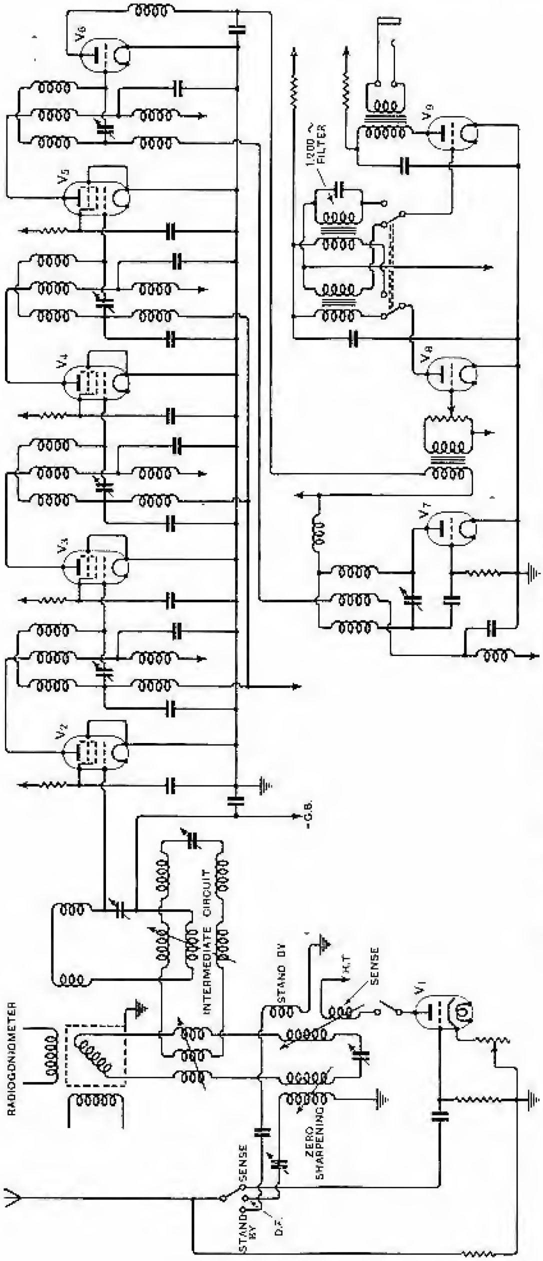


Fig. 285.—Simplified Circuit Diagram of Receiver of Fig. 283.

120). Otherwise the vector diagram is the same as that of Fig. 113.

The negative feed-back circuit (page 103) is included in the cathode lead of V_1 to maintain linearity and to reduce cross modulation.

No valve is required for the stand-by circuit as there is no phasing resistance to reduce the amplitude of the open aerial, and the open aerial and frame e.m.f.s are added in quadrature phase.

The third coupling for clearing the zero of quadrature effect is variable and calibrated on the front of the panel for +ve and —ve application of the open aerial e.m.f. The series condenser is pre-set.

Selectivity. The overall selectivity of the receiver at mid-range with the amplifier at full gain, with and without the intermediate circuit, is as follows:

AMOUNT OF DETUNE AT 240 kc.			REDUCTION IN OUTPUT VOLTAGE
Without Intermediate Circuit	With Intermediate Circuit	With Note Filter	
1·2 kc. (0·5%)	0·9 kc. (0·3%)	0·5 kc. (0·2%)	20 db. (to 1 tenth)
2·0 kc. (0·8%)	1·6 kc. (0·65%)	0·8 kc. (0·33%)	40 db. (to 1 hundredth)
3·2 kc. (1·3%)	—	2·5 kc. 1·0%)	60 db. (to 1 thousandth)

The figures for the note filter are approximate only, as the resonance curve for this condition is somewhat unsymmetrical.

Operation. Searching is done on the stand-by circuit with the intermediate circuit and note filter cut out. Bearings are taken on the cosine diagram and the two minima should be sharp and diametrically opposite. On switching to the sense connection, and rotating the pointer through 90° from a cosine minimum position, the signal will either remain about the strength of a cosine maximum or will be almost zero corresponding to the maximum or minimum of an imperfect heart diagram. When in the latter position, the short sense pointer indicates the correct cosine minimum to be observed and this is the one that should be sharpened by the zero-cleaning adjustment if this be necessary. It will be remembered that only one minimum can be sharpened by the circuit here used (page 91), but the error introduced in the reciprocal minimum is negligibly small and will not affect daytime accuracy.

The process produces a minimum such that, with the signal above receiver noise level, a pointer displacement of ±1° results in a 30 db. (32 times voltage) increase of signal strength under normal conditions.

A suitable length of auxiliary aerial is 70 feet, and it is usually found that for a rough cardioid the auxiliary aerial coupling has to be a maximum on 800 m., and minimum on 2,000 m., since the spaced aerial e.m.f. becomes weaker by comparison with the open aerial as the wave length increases.

Sensitivity. The manufacturer's figures given below are for the complete equipment using 100-feet high Adcock aerials of the shielded " U " type, with a layout as described on page 309. They are based on the assumption of an output signal sufficiently strong to take swing bearings not wider than 5°, and with a 20 db. signal-to-noise ratio at the cosine maximum. (See " Quality of Cosine Minima " on page 367).

	FIELD STRENGTH IN μV/m.	
FREQUENCY.	No intermediate circuit and using voice frequency amplification	No intermediate circuit and using 1,200 ~ note filter
150 kc.	9·4	4·1
240 kc.	2·3	0·9
375 kc.	0·9	0·4

These are laboratory results and may need increasing to approximately double for working conditions. The use of 75-foot instead of 100-foot masts is found to increase the field strength required by 4 db. (58% volts), and the introduction of the intermediate circuit about 5 db. (78% volts).

Marconi Type D.F. G.10 Receiver Modified for Use with Buried " U " Adcock Aerial and Extended Feeders. The modifications to the receiver when using extended feeders include a radiogoniometer with tightly coupled search and field coils and no capacity screen on the latter, this being replaced by the transformer screen at the aerial junction box. The radiogoniometer has a double screened case, below which is a compartment in which the feeder pairs are terminated by 60-Ohm resistances before passing to the field coil windings and the sense and zero-sharpening circuits. If the receiving gear be installed in an airport control tower, a copper strip should be run by a short path between the radiogoniometer screening case and a good earth connection in damp soil.

Input Circuit. This is shown in Fig. 286, the feeder from the sense aerial being switched to three points for sense, the removal of residual quadrature effect and stand-by. An emergency stand-by circuit is installed in case of a failure in the cables due to an accident.

Sense Determination. The phase relations for the production of a cardioid minimum can best be considered by taking the case of the actual signal minimum condition as was done for the resistance phased cardioid on page 120. In these circumstances there can be no signal in the search coil circuit and all that remains is to ensure that the e.m.f.'s in the search coil and sense coupling coil are in phase or anti-phase.

Both the spaced aerial circuit and the sense aerial are capacitative circuits, and will have leading currents, and since the e.m.f. in the former is in quadrature with the vertical electric force in the wave, whilst the sense aerial e.m.f. is in phase with the electric force, it follows that the e.m.f.'s applied to the terminating resistances of the two feeders will be in quadrature. Across the spaced aerial termination is connected a field coil winding, and, since we can ignore the effect of the search coil altogether at the zero signal condition, the field coil is a purely inductive circuit, and has a lagging current. If the search coil were similarly connected to a coupling coil, a lagging current would again be produced and the e.m.f.'s induced in the search coil would remain in quadrature. The sense circuit is accordingly tuned by the condenser C which is ganged to the receiver tuning. In order to ensure that this ganging shall hold over a reasonably wide frequency range, and also to raise the resistance of the tuned circuit to a value of about 400 Ohms, so as to be large by comparison with the 60-Ohm terminating resistance, a damping resistance R is included in the circuit.

To find sense, the D.F. pointer is turned to one of the cosine minima, the sense switch operated, connecting the sense feeder as indicated in the diagram, and the coupling M reduced to give a weak signal. The search coil is now rotated through 90° in either direction, inspecting each of the cosine minima positions with the short sense pointer, and at the same time tightening the coupling M. The position in which this operation produces the weaker signal is the true direction.

Screening. It is important that no fault occurs in the screening protection of the receiver or in the earthing system. With aerials disconnected no signal should be audible, and errors of several degrees may occur if direct pick-up is allowed to exist.

STANDARD TELEPHONES AND CABLES LIMITED GROUND STATION D.F. RECEIVER TYPE R 3

The equipment described below is intended for use with the

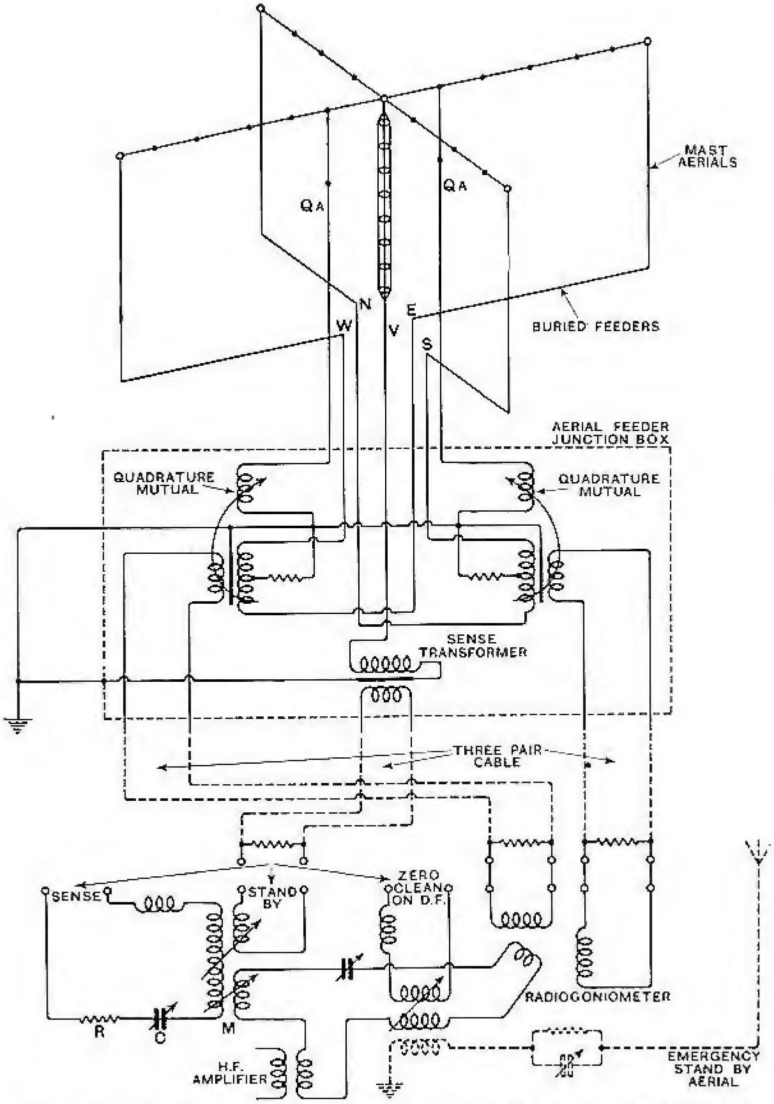
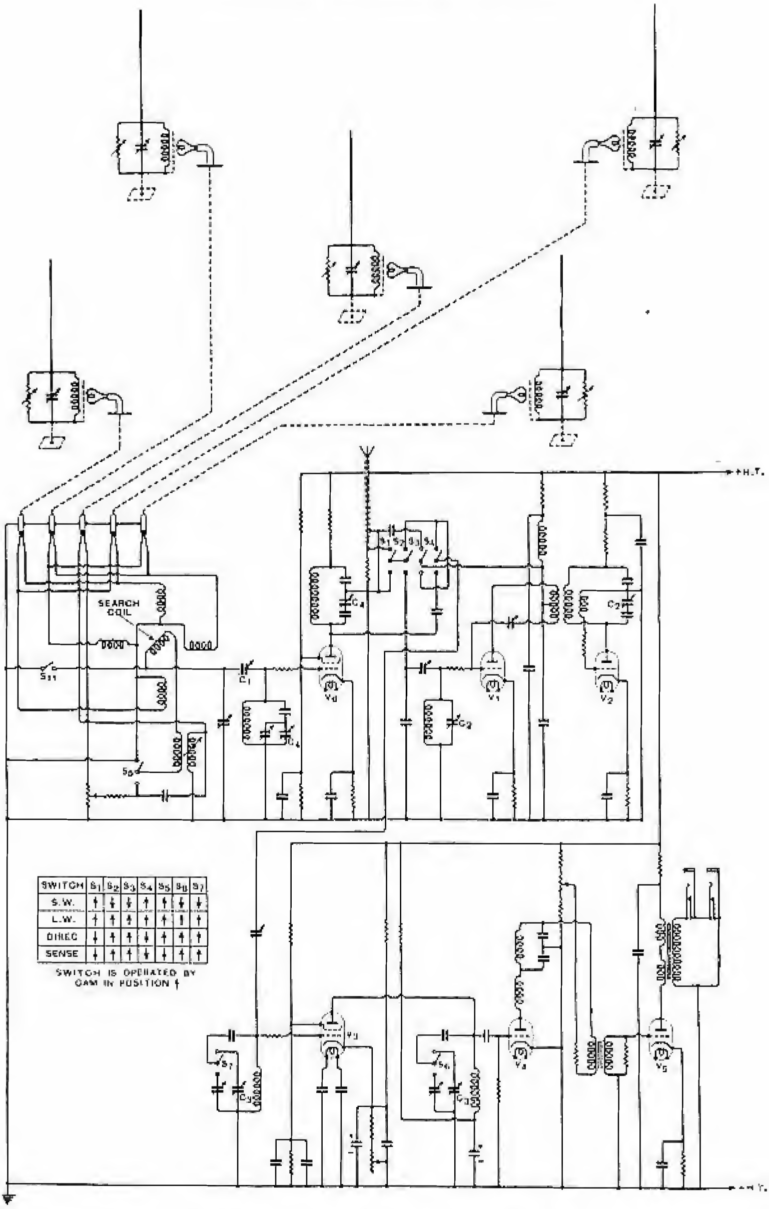


Fig. 286.—Aerial and Receiver Input Circuit for Marconi D.F.G. 10 Receiver, Using Extended Feeders.



SWITCH	S_1	S_2	S_3	S_4	S_5	S_6	S_7
S.W.	↑	↓	↓	↑	↑	↓	↓
L.W.	↑	↑	↑	↑	↑	↑	↑
DIREC	↓	↑	↑	↓	↑	↑	↑
SENSE	↓	↑	↑	↓	↓	↑	↑

SWITCH IS OPERATED BY CAM IN POSITION ↑

Fig. 287.—T.L. Aerial and Circuit of Type R.3 Receiver of Messrs. Standard Telephones and Cables, Ltd.

Adcock aerial and transmission lines to which reference has been made on page 317. It is also designed for use with a local aerial for non-directional reception of telephony and C.W. telegraphy, on long and short waves. An interesting feature of the receiver is that the radiogoniometer is constructed so as to have no octantal coupling error (see page 164).

The operation of the installation may be followed by reference to the circuit drawing in Fig. 287, which is supplied with a key plan of the switch movements mentioned later. The panel is shown in Fig. 288, and the following are particulars of the controls:

(1) Radiogoniometer.
(2) Zero Sharpening.
(3) Radiogoniometer Tuning Condenser C_1.
(4) Sense Balance.
(5) D.F. Amplifier Tuning Control, which operates on the ganged condensers C_4, C_4 in the grid and anode circuits of the first valve V_6, used only when direction finding.

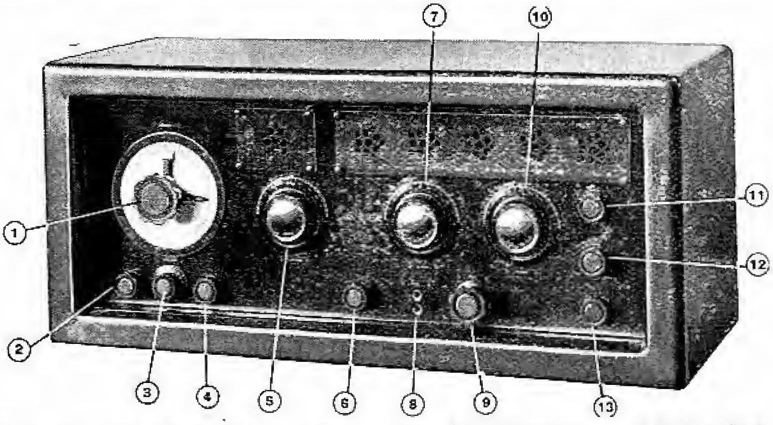


Fig. 288.—Type R.3 Receiver of Messrs. Standard Telephones and Cables, Ltd.

(6) D.F.-Transmit Switch. This is S_{11} in the circuit drawing and protects the receiver, in the case of a local transmitter, by short-circuiting the search coil winding.

(7) Short-Wave Tuning Control, operating on the ganged condensers C_2 in the grid circuit of the detector valve V_1, and C_2 in the circuit of the beat oscillator valve V_2.

(8) Telephone Jacks.

(9) Service Switch, controlling the various functions of the receiver, which include (*a*) *Long-Wave D.F.*, in which case the signals are received on the Adcock aerials and amplified by

Valves V_6, V_3, V_4 and V_5; (*b*) *Sense Determination*, for which S_5 switch transfers one earth-connected end of the search coil winding to the input circuit from the central aerial feeder; (*c*) *Long Wave Non-Directional Reception*, in which case S_1, S_2, S_4 connect the local aerial to V_3; (*d*) *Short-Wave Non-Directional Reception*, for which S_1, S_2 connect the local aerial to V_1, where the signal is tuned as stated under (7) above. Note that S_6 S_7 cut out the ganged tuning condensers of the long-wave amplifier and substitute pre-set condensers, as this is now the intermediate circuit of the short-wave superheterodyne receiver.

(10) Long-Wave Tuning Control of condensers C_3, mentioned under (9) (*d*) above.

(11) Reaction Control provided for C.W. reception and for increasing the selectivity and sensitivity of the receiver.

(12) Volume Control by variation of the grid bias of V_3.

(13) On-Off Switch.

Wave Length Range. The standard model provides D.F. service over the band 800 to 1,800 m. (375 to 166.7 kc.) and non-directional reception from 250 to 5,000 m. (1,200 to 60 kc.) in three overlapping bands. Short-wave reception, when equipped, is from 35 to 80 m. (8,500 to 3,750 kc.).

Sensitivity. The sensitivity is such that swing bearings of ±10° can be used with a field strength of 3 μV/m, using the aerial system shown in Fig. 273. The manufacturers state that this corresponds to a daytime range of about 170 miles, with ±2° accuracy, working over country typical of most of England, to an aircraft fitted with low power, that is to say, one feeding a current of about one ampere into a 200-foot trailing aerial, or approximately 20 watts aerial power.

THE TELEFUNKEN LONG- AND MEDIUM-WAVE PORTABLE D.F. TYPE E393N

This apparatus is for the reception of modulated and C.W. transmitters within the limits of 70 to 3,600 kc. (4,290 to 83·4 m.), covered by five ranges controlled by a switch. The general principles of the circuit have been described on page 128, together with a schematic diagram. Fig. 289 shows the set erected for use and it will be seen that there are two frame aerials at right angles to one another, of which one is used to provide the cosine diagram for D.F. For sense determination, the D.F. loop is disconnected and the second loop is used in combination with an auxiliary open aerial, which takes the form of a small mast rigged vertically at the centre of the loops. The use of this second loop in the plane of the received

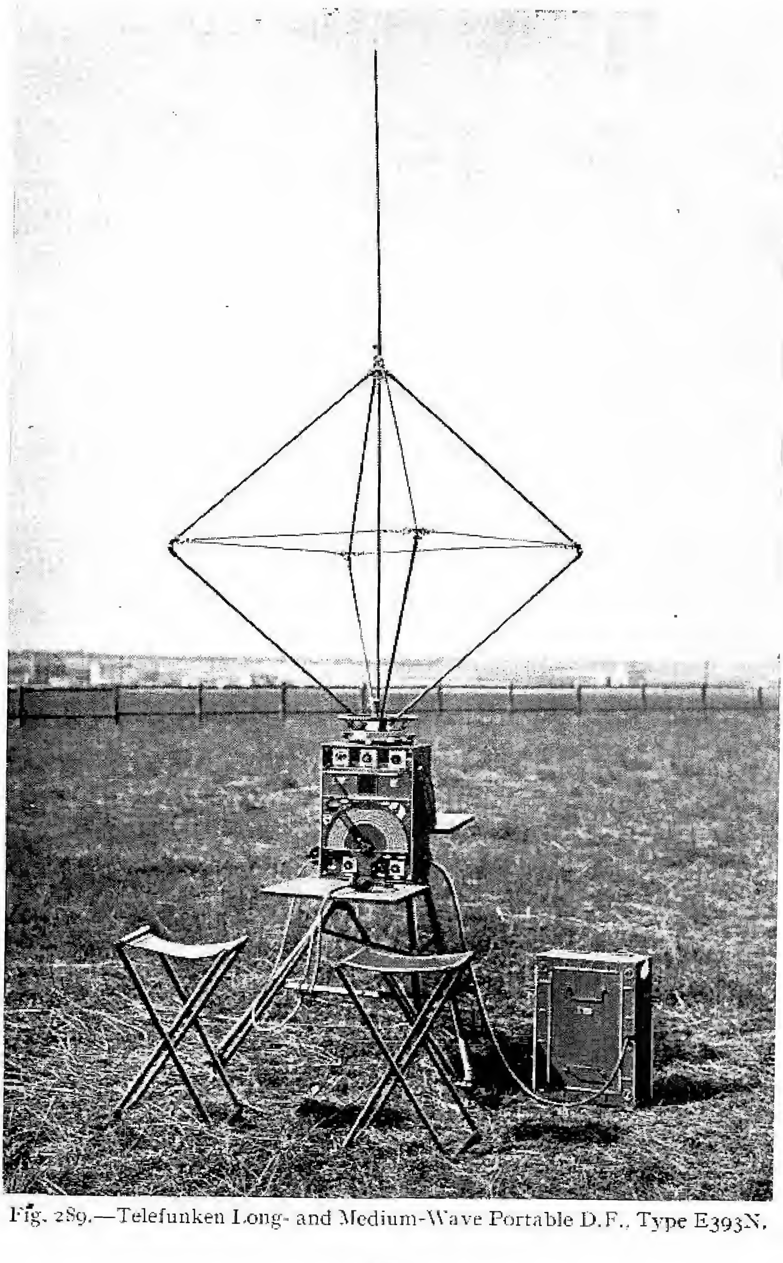


Fig. 289.—Telefunken Long- and Medium-Wave Portable D.F., Type E393N.

signal avoids the necessity for rotating the aerial system for sense determination.

Receiver. The receiver is a six-valve superheterodyne. The first three valves are the input H.F. circuit, the H.F. heterodyne and the first detector, and the three tuning condensers of these circuits are ganged with the large pointer, covering the five scales which are calibrated in kilocycles per second. There follows one stage of intermediate frequency, an oscillating detector for the intermediate frequency, and one stage of audio-frequency amplification with a fixed note of about 1,000 cycles.

A multi-range meter with a switch measures the filament heating, screen grid and anode volts, and the individual feeds of the valves. A filament rheostat in the I.F. stage is used for gain control.

The selectivity is as follows:

AMOUNT OF DETUNE.	REDUCTION IN OUTPUT VOLTAGE.
0·8%	40 db. (to 1 hundredth)
1·3%	60 db. (to 1 thousandth)
2·0%	80 db. (to 1 ten-thousandth)

The sensitivity is such that for long waves, having a field strength of 1 μV/m, or for shorter waves having a field strength of 5 μV/m, the output voltage, with the frame in the position of maximum reception, is 4 volts across a resistance of 4,000 Ohms.

Sense and Bearing Determination. The set is switched on by Control No. 11 in Fig. 290, adjusted to the appropriate frequency range by 4 and tuned by the slow motion control 1. Reaction and gain are adjusted by the controls 2 and 3, and with the switch 7 set to the yellow section (D.F.) the aerial system is rotated to the position of minimum. Control 9 is the differential condenser which is then used to sharpen the minimum, after which the bearing is noted.

For the determination of sense, a colour code is used. Two pointers are fitted to the scale of D.F., at 180° apart, so that when one of these is indicating one cosine minimum, the second pointer will be coincident with the other, and these pointers are coloured red and blue.

On switching over the control 7 from the yellow or D.F. position to the red and blue sense positions in turn, it will be found that one will give a signal minimum and the other a signal corresponding to the cardioid maximum. To determine the sense the colour is noted corresponding to the minimum sound, and the scale pointer of the same colour then indicates the sense.

General Notes. If it be desired to use the apparatus for permanent work a special aerial is supplied, for mounting through a roof or deck, whilst if main A.C. supply is available it can be arranged to work from this, although the normal equipment is a 4·8 volt battery for filaments and 100 volts for the anodes.

The total weight of the apparatus shown in Fig. 289, including batteries and stools and packed in travelling cases, is 53·8 kg. The frame aerials have a length of side of 1 m. and the open aerial mast projects 1 m. above the tops of the loops.

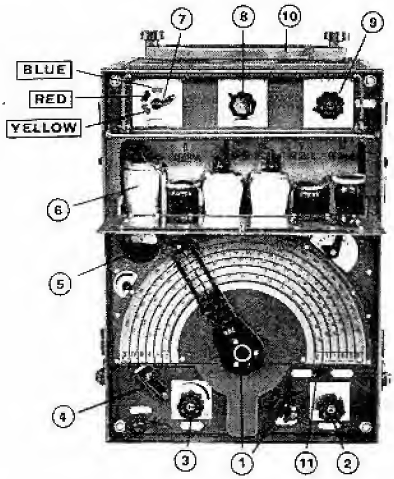


Fig. 290.—Telefunken Portable Receiver of Fig. 289.

1. Tuning Control.
2. Reaction.
3. Volume.
4. Frequency Band Switch.
5. Voltage and Valve Feed Test Meter.
6. Valves with Spring Retaining Clips.
7. D.F.—Sense Switch.
8. Cardioid Phasing.
9. Cosine Zero Sharpening.
10. Locking Device for Loop Drive.
11. On-Off Switch.

CALIBRATION

When a D.F. station has been erected and the apparatus installed and tested, the next and final process is the calibration or checking of the observed bearings at a number of points on the scale. Whether, on the one hand, bearings are taken on as many as possible known stations within the desired wave range, or whether a special mobile land transmitter, ship or aeroplane is used for the purpose, depends upon the importance of the station and type of service it is to give when completed.

Closed Loop Coastal D.F. For a rotating frame or closed loop B-T D.F. for coast work, and which is intended for day service and for short-distance night service over sea at ranges within which night effect is unlikely to occur, the calibration may confidently be done on half a dozen to a dozen transmitting stations on appropriate wave lengths, without the likelihood of serious error, provided that the site is a good one.

It is, however, a great advantage to supplement this method by taking bearings on a ship which cruises along the coast at the maximum visible range. Simultaneous wireless and optical bearings are then taken, using for the latter purpose a sextant, theodolite, or bearing plate. It is necessary to know the direction of true North in the first place, and once this is fixed the true and observed bearings may be written down and an error chart prepared for future reference. Note, however, the precautions mentioned below under "Errors Due to Transmitting Aerial."

For an inland station the problem is more difficult, and methods of locating the transmitting station must be left to the ingenuity of the person directing the trials.

When possible, the transmitting station should use the wave lengths on which the D.F. station will subsequently take bearings, as many freak effects are influenced greatly by change in wave length.

Since the range of a B-T station may easily be several hundred miles for low-power transmitting stations and a thousand miles for high-power stations, the calibration, when special transmitters are not available, can usually be performed entirely by means of bearings taken on distant stations the true bearings of which are either calculated or found from a gnomonic chart. This method of calibrating should only be carried out in daylight, as the presence or possibility of night effect renders night readings unreliable.

Errors Due to Transmitting Aerial. In Chapter 6 the possible effect of errors due to the shape of the transmitting aerial was mentioned, and errors of this class may be experienced both in the use of a portable D.F. close to a transmitting aerial, or in the use of a portable transmitter, with unsuitable aerial, for calibrating purposes when the range is small enough for the horizontally polarized component to be still effective.

In making use, for instance, of the ship as mentioned above, for calibration of a medium wave shore D.F., if the ship has an inverted L aerial it is advisable that the range should be at least five miles. A way of overcoming the difficulty is to take two sets of bearings, one with the ship travelling in one direction along the coast and the second when she is going in the reverse direction, in which case the mean of the two sets of bearings will give a closer approximation to the correct values. Alternatively the ship may be pointed to the D.F. for each bearing, in which case the source errors are very small.

This subject has been dealt with quantitatively by J. F. Coales in (3307).

The error quoted is due to the horizontal portion of the aerial, but another type of error is caused by the transmitting aerial not having a circular polar diagram. In Fig. 291 (*a*), T is a transmitter having a circular diagram of radiation, so that in any direction TR the whole of the magnetic force in the wave front is tangential, or at right angles, to the direction of propagation. A loop aerial will render correct bearings in such a case.

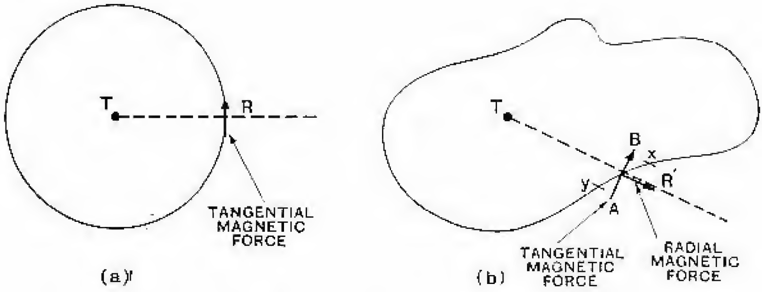


Fig. 291.—Tangential Magnetic Force near Transmitter due to Unsymmetrical Polar Diagram of Radiation.

If the aerial has an unsymmetrical polar curve of radiation as in Fig. 291 (*b*) then in the direction T R′, whilst there is a tangential component of magnetic force AB, it is clear that since the force is changing with change of direction from T, there will, at very short ranges, be a difference in the force in the area taken up by the D.F. aerial, which is equivalent to saying that there is also a radial magnetic force as shown in the diagram. In the normal frame position for a true bearing, this radial magnetic force will link with the frame, causing it to be turned to some other position for a minimum and hence producing an error.

At a distance of some miles, the dimensions of the frame aerial will be so comparatively minute that the change in the polar diagram and hence the radial field strength will be negligible.

The possibility of such causes should be taken into consideration with any transmitting stations, bearings on which exhibit unaccountable errors, and particularly in the case of transmitters used at short range for calibrating purposes.

Both types are applicable to the case of short waves and are mentioned again in Chapter 10 (3606).

Aerodrome D.F. The calibration of an aerodrome D.F. is usually a far more complex undertaking than that of a coastal D.F. for ship working, since accurate long-distance bearings are demanded day and night over land. Some of the pit-falls likely to be encountered have been discussed under "Choice of Site—Preliminaries," and the final calibration is nothing more than an extension of the site-testing operation.

The use of an aeroplane transmitter for shore station tests will, usually, be more easy to obtain than will be a ship for coast station work. This is fortunate, as the aerodrome D.F. ought, if possible, to be tested to the limit of its required range in all directions, and by day and night in the case of an Adcock installation.

So long as the test aeroplane is within visual range the optical and wireless bearings may be compared by the use of a bearing plate and, if necessary, a field telephone connection to the W/T office. If the optical bearings are taken at some distance away from the D.F., allowance must be made for parallax. The method is not easy to carry out at short ranges.

For ranges beyond visibility from the D.F., the pilot must give a land mark vertically beneath him when each bearing is taken, road crossings, buildings, etc., being usually selected, and a full programme arranged beforehand with the points marked and numbered on both the pilot's map and the station copy.

Risk of Aeroplane Effect when Testing. In the case of a closed loop D.F. the aircraft, if using a trailing aerial, should be flying either towards or away from the D.F. when the bearing is taken, to avoid polarization errors (page 192). This is of real importance, for an error of 20° or more may be observed on a loop D.F. when an aeroplane, in sight, is flying broadside to the station. A plan of flight as in Fig. 292 (*a*) is therefore sometimes adopted.

With an Adcock station, it is always desirable to have a calibration on both normally and abnormally polarized waves, and at important D.F. stations a method sometimes used is to have the test aircraft fly over each selected point four times, towards and away from the station and broadside in each direction as in Fig. 292 (*b*).

An example of the calibration of a short-wave Adcock D.F., using the above method, is shown in Fig. 320 (*a*).

THE ERROR CURVE

In every case the first thing to do, having obtained a list of observed and their corresponding true bearings, is to tabulate the results, find the errors and plot an "error curve." This curve should have a horizontal base line representing true bearings in degrees from 0° to 360°, with the vertical ordinates showing errors reckoned positive above the base line and negative below it.

If complete freedom has been possible in the choice of a site, the final selection should show nothing greater than ±1° to ±2° in the daytime for any type of aerial, and a night-time Adcock Standard Deviation (page 555) averaging, say, ±3° to 5° for the Shielded "U" aerial.

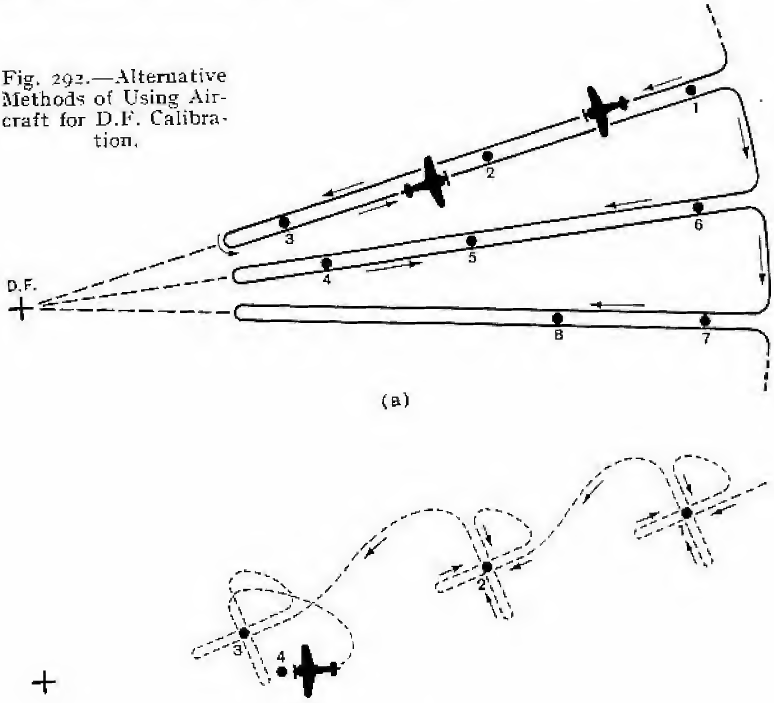


Fig. 292.—Alternative Methods of Using Aircraft for D.F. Calibration.

(a)

(b)

More probably certain directions will give trouble in spite of reasonably thorough preliminary tests, and these must be carefully examined for their possible cause, taking into account all the sources of error mentioned on pages 283 to 293.

Quadrantal Error. If a closed loop D.F. has had to be erected on a site near to a building, under a transmitting aerial or in some other altogether unsuitable position, the residual small errors will probably be somewhat masked by a large and more definite error of a well-known kind. A set of readings are tabulated below which were obtained from a station in which this was the case.

Observed Bearing.	True Bearing.	Error.
25°	21°	+ 4°
$33\frac{1}{2}$°	33°	+ $\frac{1}{2}$°
43°	45°	− 2°
58°	63°	− 5°
88°	92°	− 4°
119°	120°	− 1°
$155\frac{1}{2}$°	153°	+ $2\frac{1}{2}$°
187°	181°	+ 6°
197°	195°	+ 2°
223°	225°	− 2°
281°	285°	− 4°
333°	328°	+ 5°

On plotting the errors from the above table, it is found that the graph takes the form shown in Fig. 293 (a), maximum positive

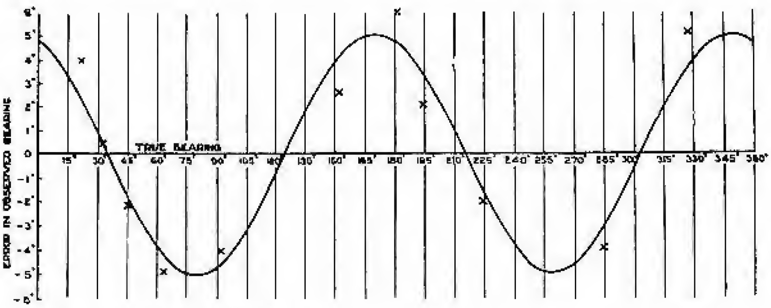


Fig. 293 (a).—Error Curve of Uncalibrated D.F.

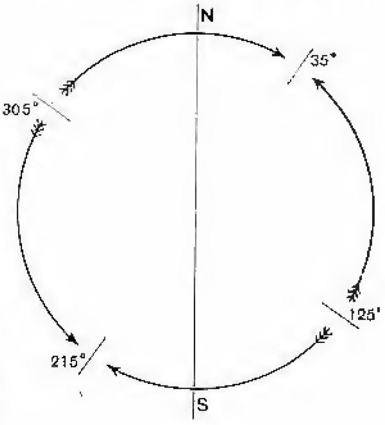


Fig. 293 (b) (right).—Drift of Bearings due to Q.E. of Fig. 293 (a).

errors being at 170° and 350°, and maximum negative errors at 80° and 260°, whilst the curve crosses the base line and hence indicates positions of no error at 35°, 125°, 215° and 305°.

For small amplitudes, this curve approximates to a sine curve or what is sometimes called a " sin 2θ " curve since there are two maxima and two minima in 360°. It should be noted, however, that the curve is actually a tangent function of the observed and correct bearings and this is mentioned again on page 435.

In the four quadrants between the directions of zero error, in the example just illustrated, there results a drift of all bearings towards the direction 35°–215°, as though the aerial system had better receiving properties in this direction. This drift is illustrated in Fig. 293(*b*), but in a steel ship installation the direction towards which the bearings are warped nearly always coincides with the centre line of the hull as in Fig. 346. In an aeroplane a similar effect is noticed, an example of which is given in Fig. 406 and 407, whilst in the case of the shore station shown in Fig. 256, excessive quadrantal error was caused by the steel masts and transmitting aerial.

In the normal shore installation, however, the phenomenon is not clearly marked and may be difficult to distinguish among other small discrepancies, but it is universally met with in steel ships and is dealt with again in that connection in Chapter 11.

ERRORS DUE TO WRONG CONNECTIONS OF B-T AERIALS TO RADIOGONIOMETER

If a set of check bearings on distant stations show absurdly large errors, being, for instance, in their wrong quadrants and incapable of being made even approximately correct by a pointer rotation, it is probable that the loops have been incorrectly connected to the field coils. If the aerial leads cannot be easily identified owing to a cable lead-in, the following methods of analysing the cross connection may be useful.

(1) Stations the true bearings of which are a certain number of degrees EAST of North appear WEST of North by an equal amount.

Reversal of leads from one aerial to radiogoniometer, which may be remedied by reversing the connections of either aerial.

(2) All Bearings are 90° Wrong.

Interchange aerials and reverse one of them. That is to say, the leads connected to the N.S.E. and W. terminals of the radiogoniometer are transferred respectively to the E.W.S. and N. terminals, or to the W.E.N. and S. terminals.

(3) Bearings are Correct only on Subtracting from 90° (or from 180° when the Observed Bearing is greater than 90°).

Interchange aerials. That is to say, the leads connected to the N.S.E. and W. terminals of the radiogoniometer are transferred respectively to the E.W.N. and S. terminals.)

In the case of a ship installation, for N.S.E. and W., read : Fore, Aft, Starboard and Port.

It may be noted that the remedies for any given errors as stated above are dependent on two factors, namely :

(1) The direction of True North relative to the plane of the frame aerials.

(2) The direction of the 0°-180° line of the scale of the radiogoniometer, relative to the planes of the field coils.

Regarding the first of these, it has been assumed throughout the book that the B-T aerials will always be laid out North-South and East-West (or in the case of a ship installation, Fore-Aft and Starboard-Port), and so it is not necessary to consider other types of layout. Referring to the second factor, the radiogoniometers mentioned in the foregoing chapters, whilst not identical in design, are so far similar that the same errors are produced by wrong connections and the remedies given above therefore apply to all of them.

The way in which the above three types of cross-connection may be recognised has been described page 160.

Practical Example of Errors in Laying Out and Connecting Up B-T Aerial. To show the confusion which may arise from lack of care in laying out the aerial system and connecting the aerial leads to the apparatus, we may instance an actual case. A temporary station had to be erected very hurriedly, and in laying out the aerials an estimate was made of the direction of North, since no compass or map was available and the sky was completely overcast. After connecting up the radiogoniometer, bearings were taken on a number of known stations, the true bearings of which were obtained from a gnomonic chart, and the results are tabulated below :

Station.	Observed Bearing.	True Bearing.		Error.
Eiffel Tower	183½°	145°	+	38½°
Cullercoats	222½°	106½°	+	16°
Malin Head	245½°	263½°	—	18°
Glasgow (temporary station)	305°	24°	—	79°
Seaforth	171½°	158°	+	13½°
Land's End	141½°	188°	—	46½°
Fishguard	144°	185°	—	41°

At first sight there appeared to be no consistency about the errors, but on applying the various remedies for cross connection of aerial leads a solution was found. On the assumption of an *East and West reversal* of all bearings the corrected bearings have been tabulated again. Thus the observed bearing of Eiffel Tower was 183½° East of North; if this be taken to be his bearing *West* of North, we get a value for the true bearing of 360° − 183½° = 176½°, and so on.

Station.	Observed Bearing.	Bearing Assuming an East and West Reversal.	True Bearing.	Error.
Eiffel Tower	183½°	176½°	145°	+31½°
Cullercoats	222½°	137½°	106½°	+31°
Malin Head	245½°	294½°	263½°	+31°
Glasgow	305°	55°	24°	+31°
Seaforth	171½°	188½°	158°	+30½°
Land's End	141½°	218½°	188°	+30½°
Fishguard	144°	216°	185°	+31°

A constant error of about 31° results from this, and it was found later to be due to incorrect guessing of the direction of North, and was corrected by rotating the pointer of the radiogoniometer through 31° on its spindle. The other fault, namely, the East and West reversal, came about through reversing the aerial leads to one set of field coils, and after connecting them properly the installation was perfectly satisfactory.

CORRECTION OF ERRORS

Elimination of Quadrantal Error in the B-T System. A quadrantal error of the dimensions shown in Fig. 293(*a*) would not occur in an Adcock installation; no such site would be selected for these aerials. With the closed loop B-T installations, however, there exists a simple way to reduce such an error to a very small figure, provided that the error curve is symmetrical, as in Fig. 293(*a*), and not of the type shown in the lower graph of Fig. 298.

If, in the B-T aerial system, one of the loops be made much larger than the other, then the e.m.f. round the larger loop and hence the current in the loop will be proportionately greater than it would be for the normal aerial. Assuming that the field coils remain symmetrical, then for any given signal arriving in a direction intermediate between the planes of the two aerials, the current in the larger frame, and hence the magnetic field in the associated field coil, will be disproportionately large, and the resultant field will be distorted. The polar diagram of the system as a receiver will, in fact, no longer be a simple figure eight curve. The effect of this upon the bearings taken at the station will be that they are all distorted towards the plane of the larger loop, and in the limit, if the smaller loop were reduced to nothing, all bearings would clearly be in the direction of the remaining frame.

When errors of this type appear and can be traced to inequality of the aerials, there are two ways in which they may be eliminated. The most obvious way is to make the frames equal in area, and the other is to put chokes in the larger loop until its receiving power is reduced to that of the small loop. This latter method is more applicable to ship installations, and is dealt with again on page 436. If the direction towards which bearings are distorted is not due to inequality of the aerials, and, moreover, does not coincide with the plane of either of the frames, then the above simple remedies cannot be applied.

Referring now to Fig. 293(*b*), it is seen that the direction in which bearings are distorted is the line 35°–215° East of North. Suppose now that the complete aerial system be rotated 35° in a clockwise direction, and the pointer of the radiogoniometer be moved on its spindle through 35° in the same direction. If the errors were actually due to some special condition in connection with the site and were entirely independent of the aerial system itself, then we have now exactly the same error curve as before, but we have also an aerial system in which the planes of the two frames lie in the directions of no error, one of which is that towards which bearings are distorted.

The symptoms are now those of an aerial system in which one frame is larger than the other, and although in this case we know this is not so, yet the same remedy may be applied, namely, that of reducing the area of the appropriate aerial. This is done by taking a few feet of wire at a time out of the aerial until the quadrantal errors have been reduced as far as possible.

Before altering the dimensions of the aerials it is wise to make certain that the distortion is not due to a fault in the aerial or radiogoniometer. Unsymmetrical loops or bad contact in one aerial circuit will give one of the aerials a greater receiving power than the other and produce such results. In the present case the direction is intermediate between the aerials, and the distortion must be attributable to some other cause. The field coils of the radiogoniometer may be at fault, but this may be easily checked by ascertaining whether the direction to which the bearings are crowded is such that when the pointer is in this position the search coil is exactly parallel to a set of field coils. Unless this is so, the possibility of constructional error is slight.

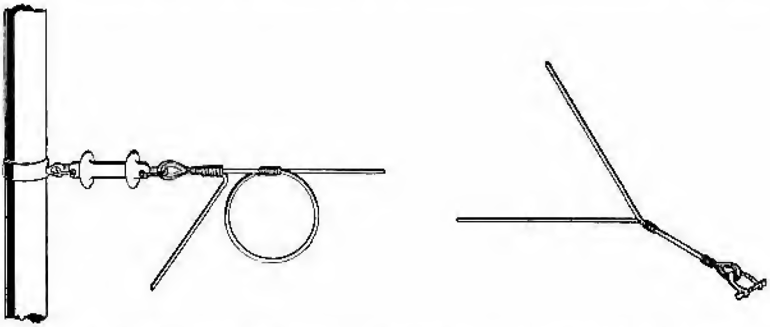


Fig. 294.—Methods of Reducing, Temporarily, the Area of a B-T Loop.

Calibration by Reducing the Area of one Frame. When making a trial adjustment on the size of the frame a bight should be taken in both lower limbs of the loop, Fig. 294 showing alternative methods of doing this. In preference to cutting and soldering the wire, it is advisable to remake the lower part of the frame altogether, modifying the dimensions in accordance with the information gained from the test.

If, for any reason, it is not desired to alter the size of the loops, a variety of alternative methods are available for either eliminating the Q.E. or making allowance for it, and these are mentioned later in this chapter and in Chapter 11.

Calibration of B-T Installation on Transmitting Station Site. Some actual figures in connection with the calibration of the installation shown in Fig. 256 will serve to show the very serious errors which are encountered when D.F. aerials are rigged under a transmitting aerial and mast system. In this particular case it was necessary that the lower limbs of the loops should be 35 feet from the ground, as the transmitting station was equipped with elevated earth wires which came out from an insulator in the roof and ran horizontally between two poles for some 30 feet and then fanned out to buried earth plates. These two poles can be seen in Fig. 256. The steel masts were 200 feet high and the down lead from the main aerial was stayed out between

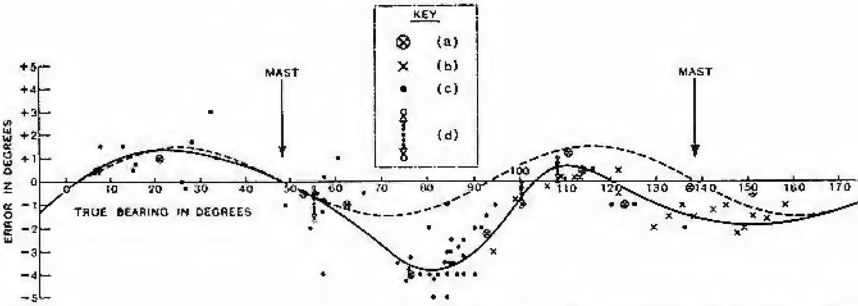
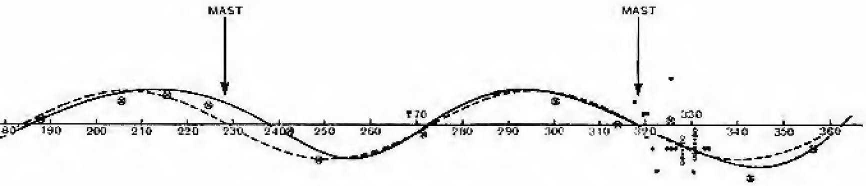


Fig. 295.—Error Curve of Medium Wa
(a) Visual Check Bearings on
Ships.
(b) Aircraft whose Positions
Known.

two of the limbs of the B-T aerial and led into the transmitting room immediately below the loops. Failure to insulate this lead where it entered the transmitting room when using the D.F., was found to cause distortion of certain bearings to the extent of 13°. Near the station was an engine room with an iron roof, two iron sheds, buried and overhead telegraph lines, buried cables and iron drain pipes and an iron fence round three sides of the site.

The centre line of the main aerial and masts was found by the method of horizontal sextant bearings and the Ordnance Survey map, to bear $47\frac{1}{2}$° and $227\frac{1}{2}$° from true North. The aerials were rigged, one exactly in line with the masts and the other, of course, at right angles and both of the same area, namely, 7,000 square feet. Since the aerial which in a normal installation would be North and South, was in this case $47\frac{1}{2}$° and $227\frac{1}{2}$°, the pointer of the radiogoniometer was moved so as to indicate a minimum at $47\frac{1}{2}$° when the " N-S " field coil was excited by a signal from a small test oscillator on the site, the " E-W " aerial being disconnected.

The first set of check bearings showed a maximum error of $12\frac{1}{2}$° with a very obvious quadrantal effect, having zero errors near the direction corresponding to the centre line of the masts. The " fore and aft " loop was accordingly reduced by the method shown in Fig. 294, by sliding the seizing up the bight of the wire to a point 16 feet from the thimble. This reduced the maximum error to 6°. A number of further modifications were made in the size of the loop until eventually when 27 feet of the bight had been taken out, the maximum error was reduced to about a degree. The aerial was then



Adcock D.F. with Octantal Component
(c) Aircraft and Ships. Positions known approximately.
(d) Fixed Stations. Showing limits of Observed Bearings.

remade to this size, which was approximately 5,000 square feet.

Residual errors still existed, but none greater than a degree, which was as good a result as could be expected in such a situation. It is very unlikely that a B-T system erected anywhere else on the site except on the centre line of the main mast and aerial system could have been calibrated to give anything approaching this accuracy as the error curve, instead of being quadrantal, would have followed some other less symmetrical law which could not be corrected by any simple means.

Correction of Quadrantal Error in Rotating Frame D.F. Another method which, like the above, can only be used to correct a true quadrantal error, is to erect a small fixed loop in the direction in which bearings appear to drift and to couple the loop to the receiver. The size of the loop and the coupling may be adjusted until an e.m.f. is injected, of such amplitude and phase, that the bearings are ' warped ' back to their normal directions.

This method was suggested by H. J. Round, both for small loops and for the Bellini-Tosi system in which latter case a third set of field coils is required on the radiogoniometer and the method becomes somewhat complex. In its application to rotating frames it has been used in a modified form in Germany and it is mentioned again on pages 439 and 513.

Octantal Error. Sometimes an error curve will exhibit a marked octantal component due to radiogoniometer coupling error and this must be taken into account in order to isolate and examine the discrepancies due to other causes. The solid curve of Fig. 295 has been plotted from the test bearings shown and has an appearance of being rather erratic. On marking in the orientation of the Adcock mast aerials, however, and plotting through these points a dotted octantal curve of 1½° amplitude, it is seen that the only doubtful sector is from 60° to 160° and the residual errors can now be taken as being the difference between the solid and dotted curves. This has the effect of altering considerably the amplitude and, in some cases, the sign of the residual errors and they may with advantage be re-plotted for further investigation.

In the site in question, coast refraction and other types of land effect appeared to be mainly responsible for the bad sector, and these were covered adequately by a correction table.

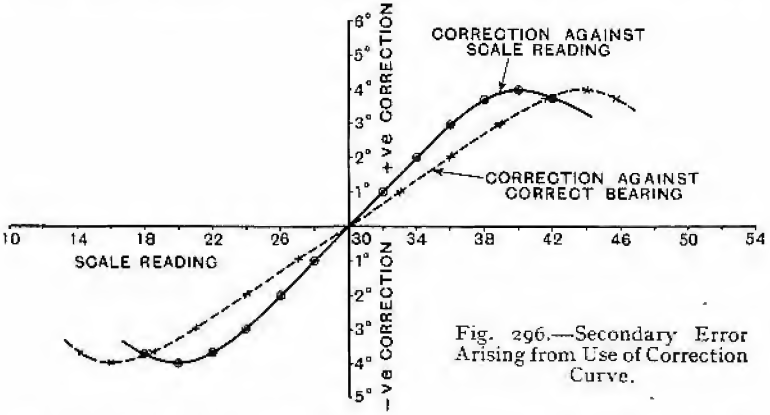


Fig. 296.—Secondary Error Arising from Use of Correction Curve.

The Correction Chart. In order to make allowance for residual errors in any D.F. system, a correction chart is used in which the sign of the error is reversed and plotted against the scale reading of the bearing, and not against its correct value. For instance, if the correct bearing be 70° and there exists an error of +2°, this means that when the D.F. indicates 72° the correct bearing is 72−2=70°. This information is most conveniently given in the form of a table, which is quicker to read than a graph.

Sources of Error when Using a Correction Chart. In the case of fairly large residual errors, having abrupt variations or changes of sign, there are two sources of possible error in using correction charts or graphs.

Below is given a series of readings covering the calibration of a portion of a D.F. scale, in which a change of error from +4° to −4° takes place between 20° and 40° on the scale :

Scale Reading.	True Bearing.	Error.	Correction.
18	14¼	+3¾	−3¾
20	16	+4	−4
22	18⅓	+3⅔	−3⅔
24	21	+3	−3
26	24	+2	−2
28	27	+1	−1
30	30	0	0
32	33	−1	+1
34	36	−2	+2
36	39	−3	+3
38	41⅔	−3⅔	+3⅔
40	44	−4	+4
42	45¾	−3¾	+3¾

The full curve of Fig. 296 shows the corresponding correction chart (that is to say the errors, with the signs changed), plotted against the scale readings. This is clearly the correct way to plot the graph, since the scale reading is the information obtained from the apparatus and it is to this figure that the correction must be applied.

The mistake is frequently made of plotting the correction against the correct true bearing which has the effect of displacing the graph laterally by the amount of the error at each point as shown by the dotted curve, and introduces discrepancies, in this instance, with a maximum of 1°.

The above error, being due to a definite mistake, is avoidable, but another of a rather different type may occur when using the correction chart illustrated.

At the point marked 30° on the scale the correction is zero, but note the effect of an observational error of plus 2°. If the bearing be read as 32°, a correction of +1° is indicated, thus increasing the error to +3°. It is true that had the correction been negative, the error would have been reduced, but the example shows the possibility of actual exaggeration of observational errors.

These instances illustrate the danger of allowing large and abrupt changes in correction to be covered by a chart. Had the total error been small, or had a large error been spread over a quadrant in a smooth curve, a 2° or 3° change in scale reading would have made a negligible difference in correction. This is yet another reason for extreme caution in the final selection of a D.F. site.

Correction Curves for Alternative Sites. On page 175 the advantage of the use of long transmission lines was mentioned in connection with the B-T installation at the British Post Office D.F. station at Niton (I.O.W.). Fig. 297 shows the neighbourhood of the station and the two sites, the original one being at the transmitting station, and the new one three-quarters of a mile distant on the cliffs.

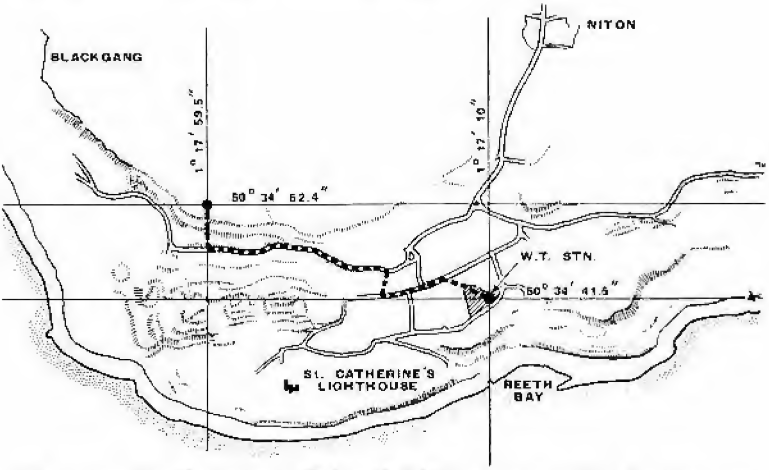


Fig. 297.—St. Catherine's Point (I.O.W.) showing W/T Station and Alternative B-T Aerial Sites (Eng. in Chief's Dept., Post Office).

The transmitting station site was a particularly bad one for D.F. aerials, owing to the very unsymmetrical shape of the main aerial and the fact that the site was overshadowed by cliffs and surrounded by buildings and uneven ground. The correction curve for this site is given for 600 and 800 m. in Fig. 298 (*b*), where the maximum error is seen to be 6°. The landward sector from 260° to 90° is not calibrated.

The " A " site on top of the cliff resulted in a curve shown in Fig. 298(*a*), where the 800 m. correction is negligible over the greater part of the useful sector, and the 600 m. correction is much reduced.

Mechanical (Cam) Correctors for Quadrantal Error. In this method the D.F. pointer and spindle of the rotating frame are not ' locked ' together but have a mechanism interposed whereby the speed of rotation of the pointer, relative to that of the loop, is advanced or retarded to allow for quadrantal or other errors. Details of this system, together with the reasons why it precludes the use of swing readings, are deferred until the ship installation sections where examples of several cam correctors are shown.

It may be noted also that the engraving of a special scale to include all necessary corrections, whilst being permissible for spot bearing, is also productive of errors with swing readings (page 445).

Lack of Symmetry Error. This error is more common in ships where long cables are used than on a shore station, but is liable to occur. It shows up as a warping of all bearings towards one point on the scale, and is described in more detail in Chapter 11.

On a carefully selected shore site there is little chance of bad lack of symmetry of the aerials, but it is not unlikely if B-T loops have to be erected near to, or under, other aerials or close to buildings.

Service Checking. It will constantly happen that, in the routine working of the D.F., bearings are taken on ships or aeroplanes, the positions of which are accurately known, and these opportunities for checking the calibration should never be neglected. If the bearings show a discrepancy, details as to date and time, etc., should be logged and it may be found that the variations are seasonal or diurnal or even due to weather

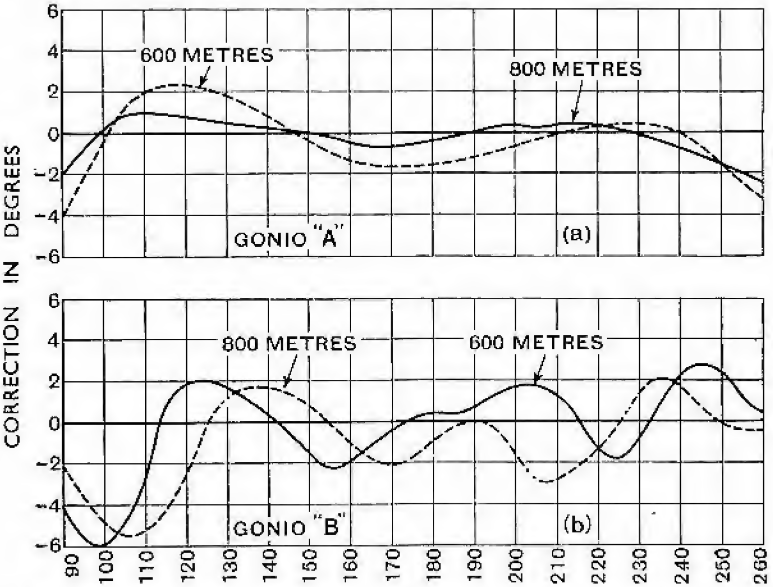


Fig. 298—Niton D.F. Correction Curves for (a) Cliff Aerial Site, and (b) B-T Loops, at W/T Station (Eng.-in-Chief's Dept., Post Office).

conditions. In any case the information, if methodically collected, will all help towards improved service, whilst re-calibration should be carried out periodically.

TAKING BEARINGS

When using the cosine diagram, bearings are always taken on minimum signals and read off in terms of **degrees east of north,** that is to say 0° on the scale is universally taken to be true North. When the whole circuit has been accurately tuned to the required station, the pointer of the D.F. is rotated to either of the points where signals vanish or reach a minimum. In many instances, a perfectly well-defined and crisp vanishing point will be found and this, as mentioned on page 84, should be 180° separated from the other equally sharp minimum. These scale readings may be taken as the required bearing, but for reasons mentioned below it is not the practice of expert telegraphists to do this, but to take swing readings instead.

Swing Bearings. This method consists in matching the intensity of the sound on either side of the point of minimum signal strength, and owing to the sensitivity of the human ear it is a singularly accurate method. In the case of a very weak signal there is no alternative to this procedure since there may be an arc of several degrees on the scale over which the signals are not heard at all, or, at any rate, the minimum is very ill defined or what has been termed " woolly."

The swing may extend over about 40°, that is to say 20° on either side of the minimum, and after some practice this can be done with great speed and accuracy. More often, the swing is a little less than this, and may be reduced to ±5°, varying with individual taste as well as with signal strength and jamming conditions on either side of the swing.

The mean of the two scale readings, where the two signal strengths are exactly equal, is the position of true minimum. Where time permits, both minima of the figure eight diagram of reception should be inspected to ensure that no antenna effect is present and if the two minima are fairly sharp but not exactly opposite to each other, then the mean of the two minima may be taken as the true maximum, the required bearing being 90° from this maximum.

Another point in favour of swing bearings is that when using a tightly coupled radiogoniometer, the coupling error, if any, is somewhat reduced by this means.

Weak signals as a reason for swing bearings have been mentioned above and in the case of aircraft ground D.F. stations this is fairly often encountered for the reasons discussed on pages 250 and 251.

Another method of taking readings about the minimum point, by means of matching sounds of equal intensity, is to adopt two search coils which are fixed relatively to one another at an angle of, say, about 40°. If now a switching key be arranged so that alternately one and then the other search coil is put in circuit, a position can be found at which the two sounds are equal and the reading of the bearing obtained without the necessity of swinging the pointer (2001). This might appear to be an improvement on the single search coil method, but experienced operators usually prefer to be able to control the extent of the swing.

Spot Bearings. What has been said above applies to the simple cosine diagram but needs modification when the diagram is rendered unsymmetrical by zero-cleaning or Q.E. compensating devices.

With zero-cleaning, this control is manipulated along with the D.F. pointer and, after one of the mimima has been made crisp, it will normally be noted that the other one is less well defined than before, though it may not be noted that the remainder of the diagram has become unsymmetrical about the sharp minimum, the reason for which has already been explained on page 91. If wide swings be taken, the minimum point will not now be mid-way between the two equi-signal positions.

Spot bearings are therefore advisable with the cleaned-up zero, although small swings of a few degrees are permissible, the extent depending upon the amount of auxiliary aerial coupling required to sharpen the minimum. The greater the e.m.f. required to do this, the greater, as a rule, the distortion of the rest of the cosine diagram.

Quality of Cosine Minima. In the descriptions of commercial apparatus in this and subsequent chapters, attempts are often made to give a measure of the quality of the cosine minima obtainable, one method being to stipulate the width of the silent arc, at the minimum, for a given field strength. Such data is not sufficiently informative and in determining the effective sensitivity of most direction finders, the points to be considered should be :—

(1) The quality of the cosine minima.
(2) The inherent receiver noise level.
(3) The intensity of the signal field, or of the equivalent test signal induced in an artificial non-radiating aerial.

The quality of the cosine minima may be specified in the form of a ratio, as for instance, 30 db. increase in signal for a ±1° displacement of the pointer from the minimum position and, assuming this rate of change of signal near the minimum, a reliable method of embodying (2) and (3) is to state that at the cosine maximum, the R.M.S. signal/noise ratio is, say, at least 20 db. for a given field strength in micro-volts per metre. Furthermore, under such conditions, and using aural reception, the receiver delivers to the telephones at least 5 milliwatts.

With regard to the width of swing bearing necessary under the above conditions, it may be noted that a 5° swing produces a signal proportional to sin 5° or 0.0872 of the maximum, which is 21 db. below the maximum. The above is therefore equivalent to specifying that at ±5° the signal/noise ratio is not appreciably worse than unity.

A more exacting specification requires that the R.M.S. signal/noise ratio shall be +3 db. at ±5° from the minimum at a stated field intensity.

Specifications of this type do not involve a silent arc and place the definition of the performance on a quantitative basis. In both cases mentioned above, the noise level is not referred to any standard audio frequency ear sensitivity scale, but is an R.M.S. value.

CHAPTER 10

SHORT-WAVE DIRECTION FINDING

Introduction. Until recently, short-wave direction finding has had more application in research work on wave propagation than for navigational purposes. The study of the sources of scattered signals, of long and short great circle path reception, of lateral deviation and other matters involving directive reception, has resulted in much information on these subjects being published during the past few years, especially in England and Japan. The apparatus perfected for this pure research is now having commercial use, and short-wave ground D.F. stations are either working or projected in large numbers in the U.S.A. and on the Imperial and other air routes of Great Britain.

The disadvantage of the wave lengths between 10 and, say, 60 or 80 m., as applied to D.F., is the uncertainty of their performance at certain short to medium ranges, by comparison with that of the wave lenths of the order of 150 m. upwards. The behaviour of this latter part of the band more nearly approaches that of the medium and long waves, and the term "short" in this chapter should be taken to apply to the 14 to 70 m. waves used for long-distance communication.

It is not to be assumed on this account that short waves have no application except at great distances. On the contrary, the strength of atmospherics in low latitudes places a limitation on the use of the longer waves, and the reflected rays of the short waves are used with advantage over distances greater than about 200 to 300 km.

Classification. Bearing in mind what has been said regarding short-wave propagation in Chapter 2, it will be understood that whilst D.F. using the ground ray alone represents a class by itself, the remaining conditions encountered do not admit of easy classification, as groups cannot easily be formed that are mutually exclusive of conditions met in the others. After briefly mentioning ground ray D.F. it will therefore be found advisable to consider the problems that arise as the

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distance between transmitter and receiving point is gradually increased. It is assumed that a closed loop D.F. is in use unless a type free from polarization error is specified.

D.F. ON THE GROUND RAY

For direction finding on short waves with a closed loop, the first essential is a vertical transmitting aerial, for only the vertical electric force can give a correct bearing, and horizontal polarization is a certain cause of error. Further, the transmitting site, the path of the ray and the receiving site should be clear of metallic masses and other obstructions. Under such conditions and until the ground ray weakens to an extent that permits of vertically reflected rays, scattered rays or low signal to noise ratio taking effect, there is a possibility of success and there are many chances of failure.

Uses of Ground Ray D.F. Owing to the short range and the difficulties encountered, short-wave ground ray D.F. is rarely, if ever, used for navigation, and its main function is what is generally known as " spy work." This includes the detection of unauthorised transmitters, varying in character from that of the unlicensed amateur to the more serious matter of the station erected in, or near to the borders of, a country during a period of war or of national emergency. In the latter type of transmitter the aerial may be anything from the vertical wire halyard of a flag pole to the horizontal dipole concealed in a street banner ; it may be in the depths of the country or on the top of a building, and in many cases there will hardly be a single available position from which a reliable bearing can be obtained.

The response of a closed loop D.F. in a city street, to the radiation from a horizontal aerial on a 100 feet high building some streets away, is likely to display " aeroplane effect " in its most virulent form with excessive errors. The only method of locating such an aerial—after its approximate position has been fonnd by means of long range bearings using a D.F. that is not susceptible to polarization error—is by the averaging of a very large number of bearings using a portable loop.

In the final stages of such a search, the D.F. may be made up in suitcase form and taken to the roofs of buildings or to any accessible point from which it seems likely that a bearing can be obtained.

Range-Limiting Factors. On wave lengths approaching 100 m., reflections are likely to be from the E instead of the F layer, and whilst affecting the bearings on the ground ray at night, they will be less effective in the day time and accurate bearings, up to ranges that are limited by the rather serious ground attenuation, may be expected on the ground ray. It will be seen later, however, that on the waves on which vertical F layer reflections occur, these reflections are liable to be one of the first limiting factors when working on open sites within otherwise reasonable ground ray range.

In the absence of reflected rays, scattered rays will be the next most serious problem, causing indefinite minima on the ground ray bearing.

Ground ray D.F. in city streets may also be affected by poor signal to noise ratio in certain areas, due to the attenuation of the signal in its passage over and through the semi-conducting masses in its path. Signal/noise ratio is, on the other hand, maintained at a high level and for greater distances over the sea, or well clear of the earth's surface. The result is that a direct ray can be received at greater ranges, and with more freedom from electrical interference, in well-screened aircraft than on the ground, where the attenuated ground ray is made still more difficult to receive by radiation from unscreened motor ignition systems, from trams, lifts and domestic electrical apparatus.

ROTATING FRAME APPARATUS FOR SHORT-WAVE GROUND RAY D.F.

Subject to the limitations mentioned above, and assuming an unobstructed site and route, the difficulties encountered in short-wave D.F. with a rotating loop differ from those met with in long- and medium-wave work more in degree than in character, and few really new problems are introduced. This branch of D.F. however, only approaches the precision of the long-wave apparatus when extreme care is paid to the following points :

Screening of all parts of the receiver, amplifier, and batteries and particularly of the heterodyne oscillator for C.W. reception.

Symmetry of the loop and input circuit.

Design of the receiving building, or mobile van, with respect to freedom from large metal masses and closed conducting loops.

Choice of site with regard to obstructions and also, to some extent, to the soil conductivity.

The reasons for these precautions have been dealt with in Chapters 4, 6, 7 and 9 and short descriptions of some loop equipment are given overleaf.

MARCONI PORTABLE SHORT-WAVE D.F. TYPE D.F.G.15

This apparatus covers a wave range of 15 to 200 m. (20,000 to 1,500 kc.) and is contained, complete with batteries, in a metal cabinet, in the centre of the top of which is a mounting for two interchangeable rotating frames of one and three turns respectively. They are about 2 feet square and are mounted with a diagonal vertical, and have provision for series or parallel connection of their windings to cover the wave range. Insulated flexible wire is used for the winding, which is mounted on a folding wooden frame. The loop tuning condenser is at the top of the frame, enabling the diametrically opposite point of the loop, namely the centre of the coupling coil, to be earthed. Sense determination is not provided.

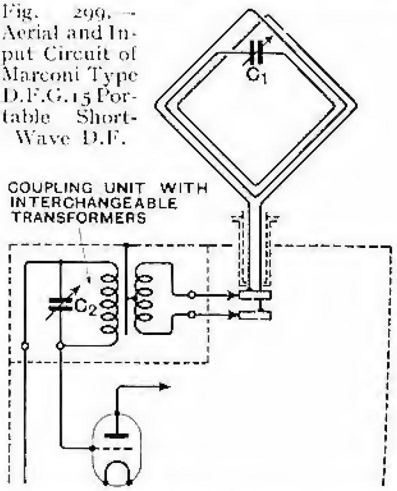


Fig. 299.—Aerial and Input Circuit of Marconi Type D.F.G.15 Portable Short-Wave D.F.

Five coupling transformers are used and each has an earth-connected capacity screen as shown in Fig. 299, the unit being mounted, complete with secondary tuning condenser C_2 in a separate screened compartment. The receiver is a conventional superhet. type, equipped for telephone or telegraph reception.

Operation. It is found that the improvement in the sharpness of the cosine minimum, to be gained by connecting the screening case to earth, depends on the location and should be decided by trial. In any case, the earth lead must be short. The operator should not obstruct the frame more than necessary, and any bystanders should also keep well clear, symmetry in the immediate neighbourhood of a small frame being important on short waves due to screening and re-radiation produced by conducting masses. Other obvious precautions are to keep the slip ring connections clean and to ensure that all screening compartments are securely shut.

THE TELEFUNKEN GROUND RAY SHORT-WAVE PORTABLE D.F. TYPE P 57 N

This apparatus is designed for use up to about 30 km. from a short-wave transmitter, is comparatively weatherproof, or is capable of giving fair results when mounted in a motor van, subject to the precautions already mentioned. Details of the controls are made clear in Fig. 300 and the key plan of Fig. 300 (*a*).

Receiver and Circuit. A simplified circuit diagram is shown in Fig. 301. The input circuit is of a conventional type, consisting of a transformer coupling between the loop and first valve, the secondary of which is tuned by one of a set of ganged condensers with suitable trimmers. This valve V_1 is an R.F. mixing valve for the signal and the R.F. oscillator V_2.

The trimming condenser C_1, balancing condenser C_2, the transformer and also the resistances R_1 and R_2 and switch S_1 for producing the unilateral diagram for sense determination, are seen to be enclosed by a dotted line, and they form an assembly that is interchangeable for the three frequency ranges, which are as given below :

I	3 to 6 M.c.	(100 to 50 metres)
II	6 to 12 ,,	(50 to 25 ,,)
III	10 to 20 ,,	(30 to 15 ,,)

The R.F. oscillator coils and some associated components are also interchangeable in the same way. The switch S connects the open aerial to the zero-sharpening condenser C_2 or, when S_1 is closed, to the grid of V_1 for sense determination.

The remainder of the circuit is not shown but valves V_3 and V_4 are the intermediate frequency amplifier and detector and are followed by two stages of audio amplification. The second detector may be used as an oscillating detector. The ganged tuning condensers are operated by the tuning index, 11 in the plan, the three frequency ranges being engraved on the scale in megacycles per second and are accurate to within 0.5 %.

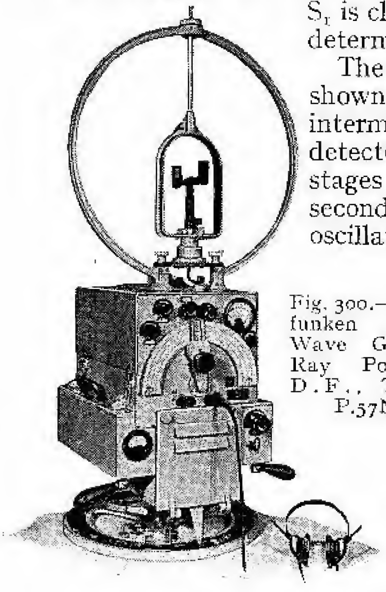


Fig. 300.—Telefunken Short-Wave Ground Ray Portable D.F., Type P.57N.

Sensitivity and Selectivity. The sensitivity is such that a field intensity of $5\mu V/m$ will produce an output of

3 volts across a 4,000-ohm load with the loop in the position of maximum.

When using the apparatus on the ground ray with a field

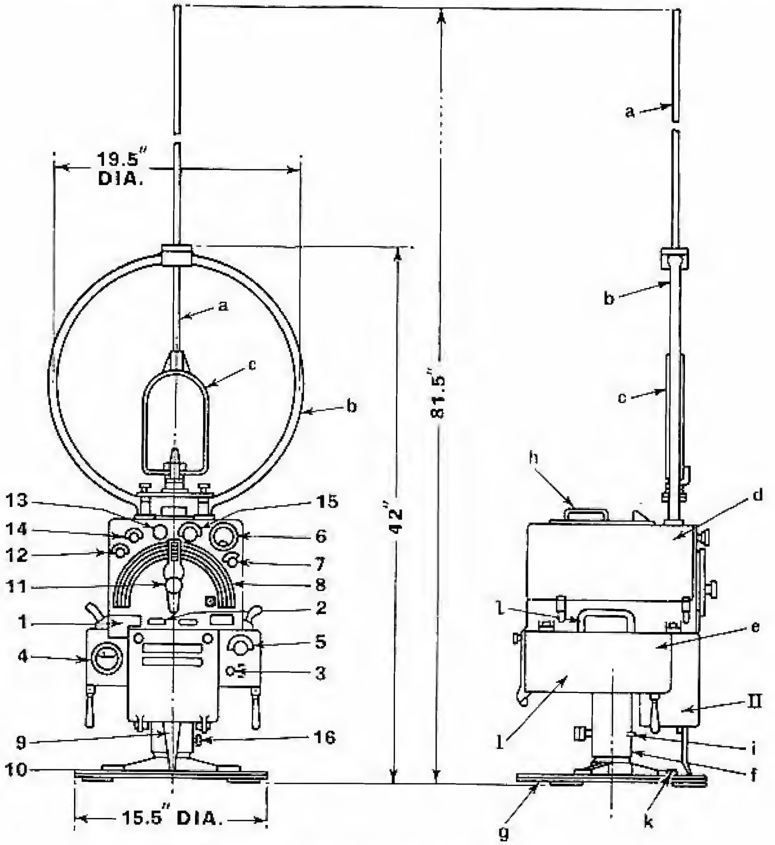


Fig. 300 (a).—Key plan of Fig. 300.

CONTROLS.

1. Battery Connections.
2. Telephones.
3. On-Off Switch.
4. Voltmeter.
5. Filament Rheostat.
6. Output-meter.
7. Control for Measuring Range.
8. Tuning Scale.
9. D.F. Pointer.
10. D.F. Scale.
11. Tuning Handle.
12. Reaction Control.
13. Zero Sharpening.
14. Volume.
15. D.F.—Sense.
16. Locking Screw.

COMPONENTS.

a. Auxiliary Aerial.
b. Loop.
c. Metal Frame holding Diopter.
d. Receiver.
e. Battery Box with—
   Anode Battery I,
   Filament Battery II.
f. Pivot Bearing.
g. Base with D.F. Scale.
h. Interchangeable Coil Box.
i. Locking Screw.
k. Spirit Level.
l. Carrying Handle.

strength of $5\mu V/m$, the total arc of silence at the cosine minimum is about 10° and is about 1° with a field of $50\mu V/m$.

The selectivity of the amplifier for various degrees of detuning from resonance is as follows :

AMOUNT OF DETUNE.	REDUCTION IN OUTPUT VOLTAGE.
0·2%	20 db. (to one-tenth)
0·5%	40 db. (to one-hundredth)
1·1%	60 db. (to one-thousandth)

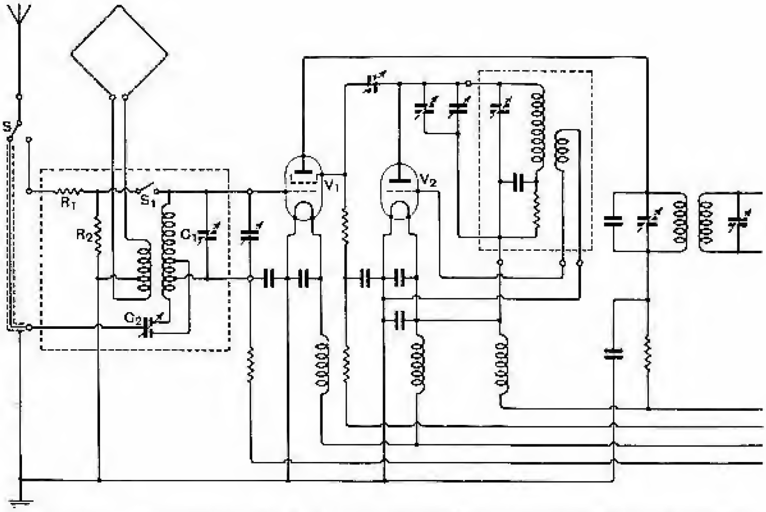


Fig. 301.—Aerial and Input Circuit of Telefunken Short-Wave Portable D.F. of Fig. 300.

Batteries. A 4 volt, 0·5 ampere accumulator for filament heating, and a 150 volt 25 m.a. dry battery for anode voltage and grid bias are used.

Mode of Operation. For use in the open, a tripod is supplied, and the scale is correctly orientated by optical means, after being carefully levelled. The component, called in the key plan the ' diopter,' is a sighting device similar to that used with a prismatic compass, and a compass with tripod is also supplied. The latter is erected a short distance away and visual bearings are taken from the D.F. to the compass and vice versa. This is illustrated in Fig. 302, where the compass has been sighted on the D.F. from P, and the D.F. on the compass from Q. Allowing for magnetic variation, the bearing of the D.F. at the compass is, say, 65°, and it is then only necessary to rotate the scale of the D.F. so that the diopter pointer is at 65°, and the 0° on the scale will be true North. It is, of course, impracticable to have the compass incorporated in the design of the D.F. owing to the iron transformer cores.

There are two D.F. scales, a red and a blue one, having engravings differing by 180°, and it is the red or main scale which has its 0° directed to the North.

Sense Determination. The zero cleaning and taking of bearings are straightforward, unless the D.F. is working on a bad site or near to the limit at which reflected rays begin to take effect and to cause blurred and wandering minima. Assuming the cosine minima to be normal, sense is found by moving the Bearing/Sense switch to the appropriate contact—marked red and blue—and then rotating the D.F. pointer alternately to right and left by about 30°, and noting the strength variations. There are red and blue arrows, corresponding to the directions of rotation, and the colour which tallies with the weaker direction indicates which scale—red or blue—is to be used when reading the cosine minimum, and will give the bearing and sense.

Relative Distance Measurement. In the transformer secondary of the final audio frequency amplifier valve, is an A.C. output meter, as shown in Figs. 300 and 300 (*a*). For approximate relative distance measurement, an appropriate

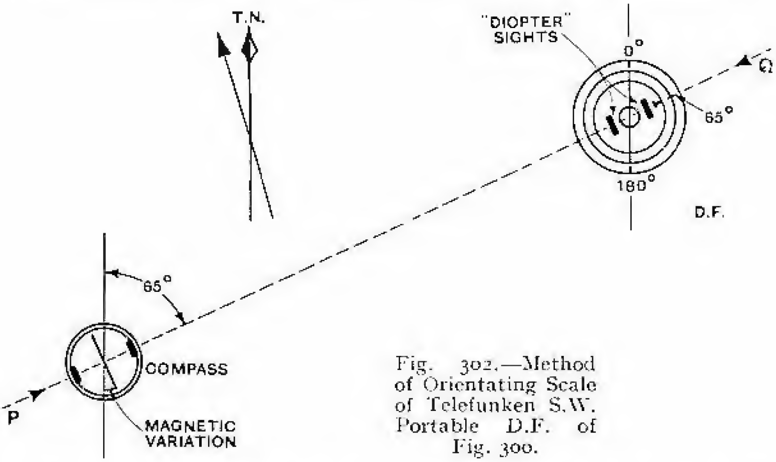


Fig. 302.—Method of Orientating Scale of Telefunken S.W. Portable D.F. of Fig. 300.

range is chosen and the volume control adjusted until, when the loop is at the maximum position, the output is 1·5 volts on a steady mark from the transmitter, or on a recognizable signal sequence that can be relied upon to be repeated fairly often. Now, when moving the apparatus to the next point, increasing output will usually mean that the D.F. is approaching the transmitter.

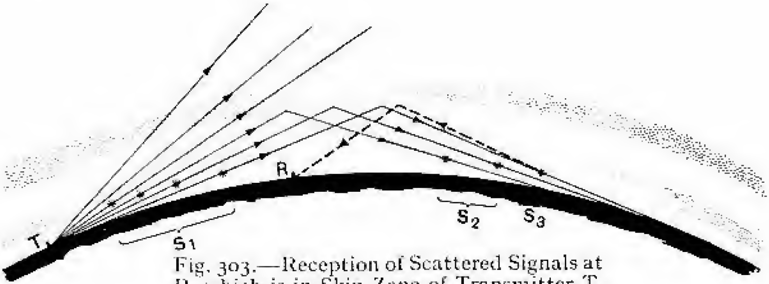


Fig. 303.—Reception of Scattered Signals at R, which is in Skip Zone of Transmitter T.

Weight. The complete equipment, packed in a special box and with canvas cases for the tripods weighs 192 lb.

SHORT-WAVE D.F. AT INCREASING RANGES

At increasing ranges, varying with terrain, the ground ray on the shorter waves will be rapidly attenuated, and reflected rays and scattered radiation will begin to take effect. These introduce indefinite minima and the liability to error due to abnormal polarization and also, in the case of scattering, due to the signal not arriving on the great circle path from the transmitter.

Errors Due to Scattered Radiation Alone. The theory of the origin of scattered radiation has been mentioned on page 43, where it was observed that in the case of a non-directional transmitting aerial, scattered rays might return from any direction in which propagation conditions were favourable. The effect of such rays arriving from random directions will be to produce a blurred cosine minimum or, in the extreme case of signals from many directions, a condition in which no bearing is discernible. Fig. 303 shows how the scattered signals reach the receiving point R in the skip zone. This diagram cannot conveniently be drawn to scale, but if this were possible, it would be seen that the dotted path is that of one of the first scatter signals that can possibly reach the point R. For the near scatter sources S_1 and for the distant scatter sources of the higher rays as at S_2, R is assumed to be in the skip zone. The S_3 sources are far enough away for their reflected rays to reach R.

It has been mentioned in Chapter 2 that in the case of a directive transmitting aerial the scatter rays were also directive, and the results of this may be very disconcerting. Instances are not uncommon in which, although no propagation along the great circle from transmitter to D.F. is possible by either long or short path, consistent and well-defined bearings can be obtained from totally inaccurate directions.

The same thing may occur when great circle connection with the D.F. is prevented by the use of a beam transmitting aerial directed elsewhere or, in yet other instances, correct and incorrect bearings may be obtained simultaneously.

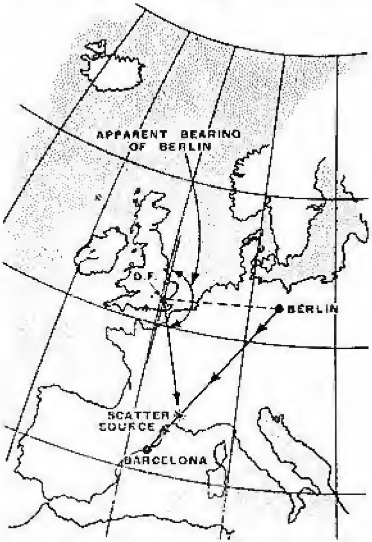


Fig. 304.—Incorrect Bearing of Berlin due to Scatter Sources on Berlin-Barcelona Beam Route.

Fig. 304 shows a D.F. receiver at Chelmsford, Essex, at which bearings were taken of a transmitter in Berlin, the true bearing of which is 81°, yet under certain conditions there was a fairly well-defined bearing obtained at about 150°. The explanation of this is that the transmitter in question had a beam directed on Barcelona and the radiation in other directions was negligible, thus accounting for the absence of true bearings, but at some point between Berlin and Barcelona there was scattered radiation, and this was received in England and produced the distorted bearing.

A second case is that shown in Fig. 305 in connection with the Imperial beam route from Kirkee, India, to Skegness receiving, station the route then passing across the Atlantic in the direction of the West Indies. At times, when attempting to take a bearing of Kirkee from Chelmsford, the sense and direction were in mid-Atlantic as well as normal. This was not due to the back radiation of the beam, as the long route was unsuitable for the wave length in use, but was due to scatter sources in the route of the signal after passing England.

A third illustration, this time of an error of 90°, is shown in Fig. 306. At certain times, a 30 m. wave, whilst useless for working between New York and London, is suitable for both New York-Buenos Aires and also the London-Buenos Aires

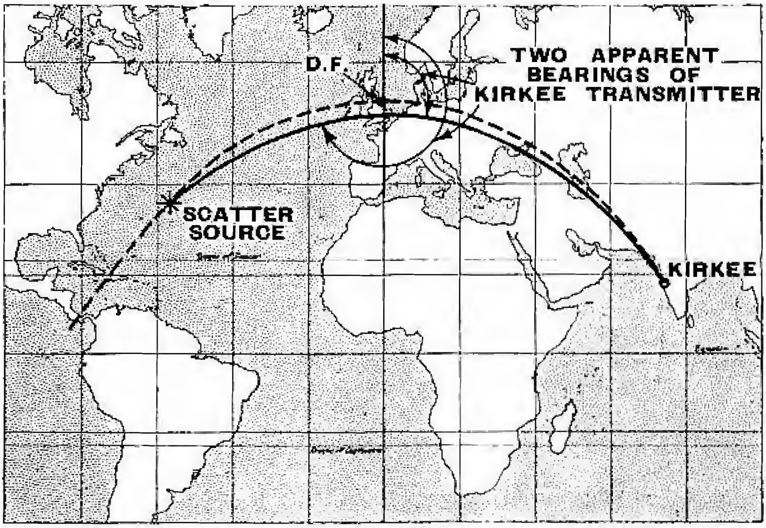


Fig. 305.—Reciprocal Bearings of Kirkee due to Scatter Sources in Atlantic Ocean.

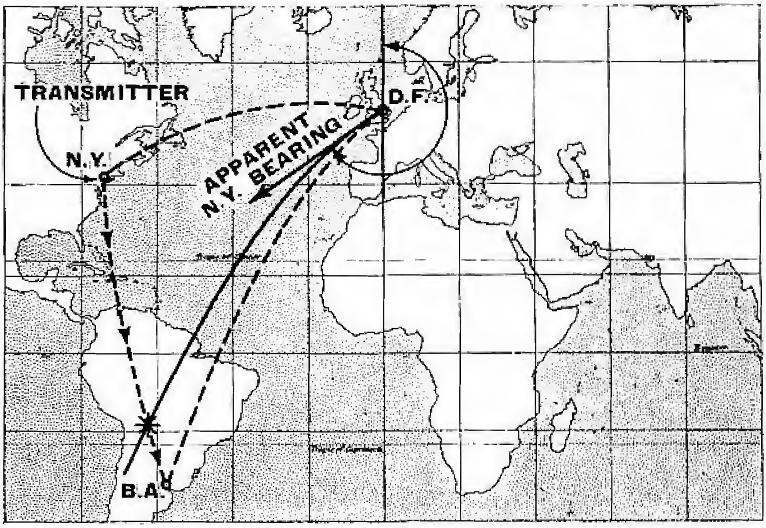


Fig. 306.—Incorrect Bearing of New York due to Scatter Sources on New York-B.A. Route.

circuits. If a bearing be taken from London of a New York transmitter working to B.A. under such conditions, it is impossible to get a true bearing of New York, as there is no signal from that direction. On the New York-B.A. route, however, there may be scatter sources and from one of these points near the southern end of the route, conditions will begin to be suitable for 30 m. transmission to England, and so from this source the radiation reaches the D.F. and gives an apparent bearing of the New York transmitter.

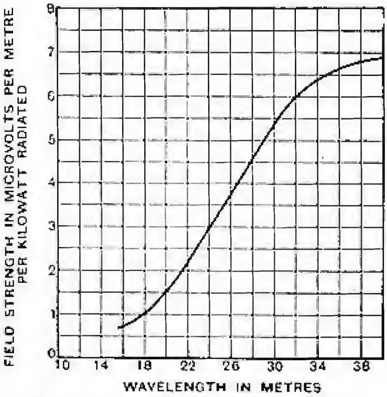


Fig. 307.—Field Strength of Scattered Signal (see text).

Scatter from non-directional aerials may also have a bearing. If the propagation conditions were entirely symmetrical in all directions from the aerial, the scattering would return symmetrically and produce no bearing. Scattering, however, like the main radiated signal, obeys the laws of propagation, as dictated by the conditions along the various paths, so that scatter sources will vary very much with the time of the day and season. The great danger of bearings of scattered radiation remains that there is often nothing to indicate that the bearing is not a correct one, and it is clear that in order to be able to interpret these vagaries of scattering and so to set one's mind at rest regarding bearings that often bear no relation to the true direction, it is helpful to have a fairly comprehensive knowledge of the laws that govern long-distance short-wave communication.

Scattered Signals plus Ground Ray. Referring again to Fig. 303, when the ground ray extends to the receiving point and is comparable in strength with the scattered rays, the definition of the ground ray minimum will be rendered indefinite and this fixes a limit to its useful range. Since the strength of the scattered rays varies with propagation conditions over the route, the useful ground ray range will be variable and some idea of the intensity of scattered signals can be had from Fig. 307 which shows the field strength, on varying wave lengths, for one kilowatt radiated. The conditions are for mid-day and Lat. 50°N. and with the transmitter situated at such a distance that the receiver is in the skip zone.

From the low field strengths it will be realized that on powers of 100 to 200 watts, scattering is not likely to be troublesome. When, however, the range and conditions are such that scatter interference is experienced, there will usually be nothing to be gained by an increase in transmitter power, since the scattering will increase in strength in the same proportion as the wanted rays.

High Angle Reflected Rays plus Ground Ray. The conditions for vertical reflection have been mentioned on page 35 and the results illustrated in Figs. 26 and 27. When using a closed loop, these reflected rays limit the range of the ground ray D.F. far more drastically than does scattering, as the former are usually of greater field strength and have no zero on a loop placed in the normal cosine minimum direction of the transmitter.

As examples of this effect it may be mentioned that a 20 kW transmitter, working with a horizontal dipole aerial and using a 39 m. wave length, was found, at a distance of 19 km. to have a first F layer reflected ray 10 db. (× 3 voltage) up on the direct ray, together of course, with several further reflections.

Again, in the case of a $\frac{1}{4}$-kW vertical dipole transmitter sending pulses on 50 m. wave length, the ground ray, although still having a field strength of $6\,\mu$v/m at a distance of 75 km., was useless for aural D.F., even at 15 km., due to vertical reflection. This is a case where the pulse direction finder (page 223) is of immense assistance.

Varieties of Reflected Ray. In Fig. 308 (*a*), (*b*) and (*c*), are illustrated the types of reflected ray that reach a receiving point R as the wave length is progressively increased.

With a 40 m. wave length in the day-time there will usually be 1st, 2nd and possibly 3rd order F rays, together with the ground ray if the range is not too great. (2nd and 3rd order rays here refer to 2nd and 3rd reflections from the F layer.)

An increase to 70 m. in Fig. 308(*b*) may introduce E layer in addition to F layer reflection, and 1st and 2nd E and F rays are shown, together with the possibility of the ground ray, which will have an extending range with increasing wave length.

Further increase in wave length results in loss of F layer reflection, as in Fig. 308(*c*), whilst at 200 m., the ground ray is likely to be present up to ranges of between 200 and 400 km.

As already stated, with increasing ranges up to great distances, the trajectory of the reflected rays becomes progressively flatter and polarization errors correspondingly less serious.

Effect of Transmitting and Receiving Aerial on High Angle Ray Reception. A transmitting aerial having a polar diagram with a low trajectory will greatly increase the ratio of ground ray to vertical reflected ray, though it will also probably increase the strength of long-range scattering which is produced by low angle rays.

An effect of change of aerials was observed in connection with the pulse transmissions illustrated in Figs. 26 and 27. Although the ground ray and first reflection appear equal in each of the oscillograms, there was actually limiting to the extent of 40 db. in the ground ray image, which should, therefore, have been about 100 times the height of the first reflection image. When the transmitting aerial was changed from a vertical one to a horizontal dipole, still retaining a vertical receiving aerial, the intensities of the ground ray and first reflection became equal. This was due to an increase of approximately 20 db. (10 times voltage) in the reflected ray and a similar decrease in the vertically polarized component of the ground ray.

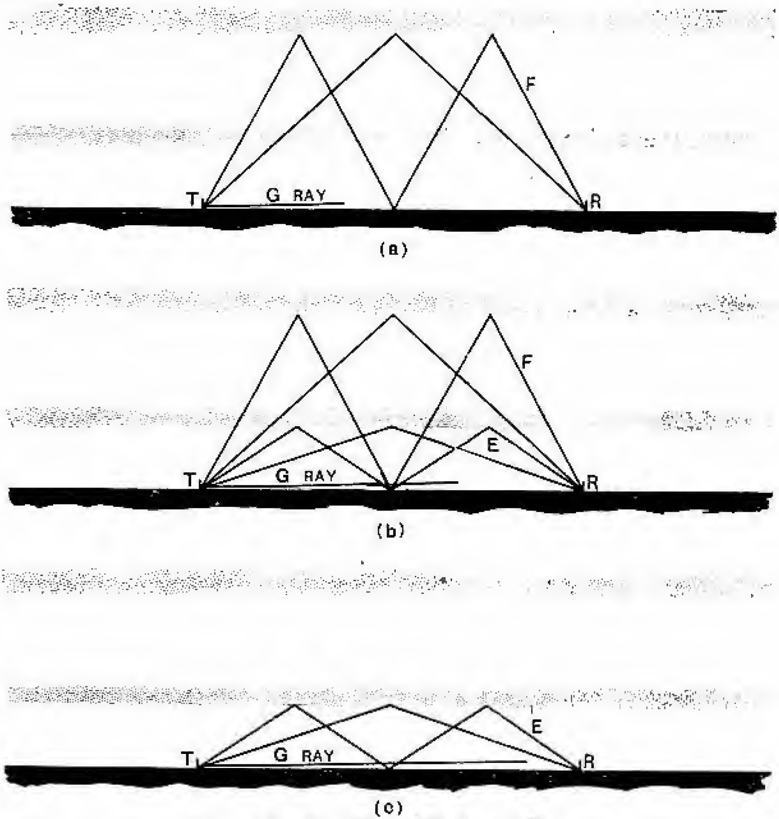


Fig. 308.—Varieties of Reflected Rays.

Conditions such as those last mentioned could not be expected to yield any intelligent D.F. information using a closed loop.

Errors Due to Reflected Rays. The ill effect of high angle rays may be judged from the fact that, with a loop D.F., a reliable bearing cannot be taken on a ray making an angle with the ground greater than about 5°. If a ground ray is present, the extent to which bearings are distorted will depend upon the relative intensities of the ground ray and reflected rays, but the presence of a vertically incident ray of 5 % of the strength of the ground ray will distort the bearing of the latter by about 3°.

THE ADCOCK AND SPACED FRAME AERIALS

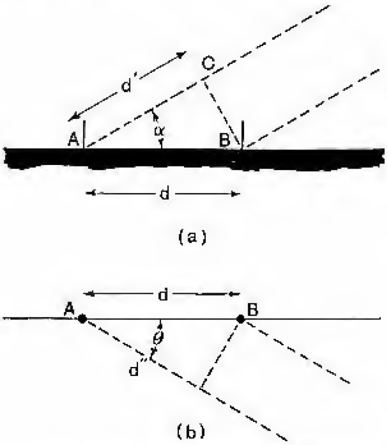
Whilst the conditions for short wave D.F. have so far been discussed mainly with reference to the loop, this was in order to draw attention to its limitations and not because it is used at all extensively. As the range is increased beyond that of the ground ray, the skip zone is reached, in which it has been seen to be impossible to take any accurate bearings by existing methods since the only signals received are from scatter sources. A still further increase in range brings the first reflected rays, and the greater the wave length, the shorter the skip distance and the steeper the angle of the first rays received—up to the wave length at which E layer, instead of F layer, reflections begin to take place.

Even on short waves, however, the first rays received will make an angle with the ground much in excess of the 5° maximum permissible for closed loop D.F., and thus its use is limited to the ground ray at very short ranges and to great distances when the path of the reflected rays becomes very nearly horizontal.

The Adcock aerial has been developed for use on all ranges except those where the angle of the reflected ray with the ground exceeds about 60°. Higher angle rays than this cause special difficulties in the use of the screened or buried " U " type Adcock aerial, as explained in Chapter 7. The angle of the ray in these circumstances is such that whilst the aerial pick-up of the vertical component of the electric force available for useful reception on the Adcock is small, necessitating high receiver gain, the pick-up of the horizontal component, which induces screen currents etc., remains normal and results in poor performance.

Above 60 or 70 m., in the day-time, there is a likelihood of E instead of F layer reflection, and with this comes a marked improvement in the angle with the ground so that the Adcock tends to become more free of polarization error as the wave lenth increases.

D.F. with high angle rays, however, requires an aerial in which feeder pick-up is completely balanced out, such as possibly the elevated "H" or the Balanced - Coupled types of Adcock, though the use of such systems in commercial service over a wide range of wave lengths would again lead to other problems.



(a)
(b)

Fig. 309.—Spaced Aerial Reception.

There appears to be here a case for the use of balanced frames, as already mentioned briefly on page 220, with their advantage of good pick-up of vertical polarization, even with high angle rays, and a description is given below of the Eckersley-Marconi short-wave spaced frame apparatus.

SPACED FRAME SHORT-WAVE DIRECTION FINDER (ECKERSLEY-MARCONI)

In references (3503) and (3606) T. L. Eckersley described the development of a spaced frame aerial array which, in its more recent form, has proved capable of precision as a short-wave D.F. under the adverse conditions of high angle rays.

If A and B in Fig. 309 (*a*) be two aerials spaced a distance d apart on a horizontal plane and in the vertical plane of propagation of a plane wave, the linear distance d' between them in the path of the wave results in an angular phase difference of $\frac{2\pi d'}{\lambda}$ or $\frac{2\pi d}{\lambda}\cos\alpha$, where α is the angle made by the ray with the ground.

Similarly, if Fig. 309 (*b*) shows the plan view of the aerials, with a plane wave arriving such that the horizontal ray angle with the line of the aerials is θ, then the difference of phase of the e.m.f.'s is proportional to d'' and equals $\frac{2\pi d \cos\theta.}{\lambda}$

For a wave combining a vertical angle of elevation α and a horizontal angle θ, as shown, the phase difference at A and B will therefore be $\frac{2\pi d}{\lambda}\cos\theta\cos\alpha$.

Leading the aerial signal into a central phase adjustor, and obtaining an artificial phase balance, would give a measure of the quantity $\frac{2\pi d}{\lambda}\cos\theta\cos\alpha$ and hence of $\cos\theta\cos\alpha$. Knowing either θ or α the other could then be found; for instance, α, the angle made with the ground, could be found for transmitters whose position and hence whose azimuth were known, and alternatively the horizontal angle θ would be given where the ray path was known to be nearly horizontal.

For reasons mentioned in Chapter 7, there is difficulty in avoiding a transfer of energy to the aerials, from the shield of the horizontal connecting cables or feeders, which are influenced by the horizontally polarized component in the wave. This energy transfer will upset the accurate measurement of the phase difference at A and B, but Eckersley pointed out that it can be avoided if frames are used instead of open aerials, provided that they are arranged with their planes at right angles to the vertical plane through the connecting feeder, and exactly symmetrical about this plane as in Fig. 310.

This arrangement has the additional advantage over the spaced open aerials that the ambiguity due to the combined effects of the angles of elevation and azimuth is eliminated. If the system is made rotatable and is turned until zero signal occurs on a given transmitter, assuming that the zero remains constant, that the receiving apparatus is exactly mid-way between the frames and there is no artificial mis-phasing, then the direction of the transmitter must be at right angles to the plane through the connecting feeder. It is assumed that there is no "source error" (page 398) and that the wave front is everywhere normal to the radius from the transmitting aerial.

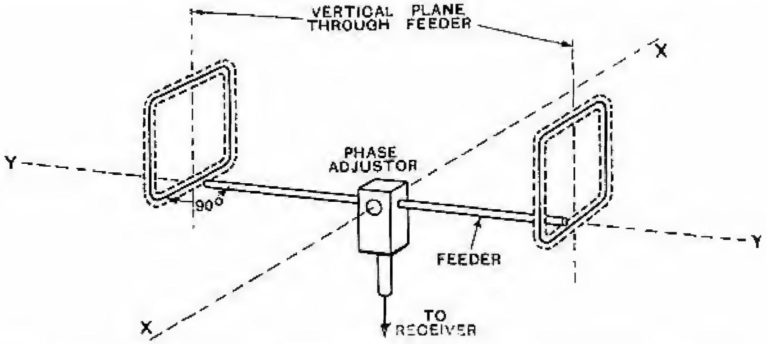


Fig. 310.—Principle of Eckersley-Marconi Spaced Frame Short-Wave D.F.

Elimination of Polarization Error. The extent to which spaced frames could be used to obtain correct bearings under conditions which made the simple frame subject to polarization error has been mentioned on page 220, and the arrangement of Fig. 311 is equally effective for short waves, and may be seen to be incorporated in the apparatus in Fig. 312 for use in certain circumstances. Here again however it is essential to dispose the feeders in such a way that there is no transfer of energy, the arrangement shown being effective in this respect.

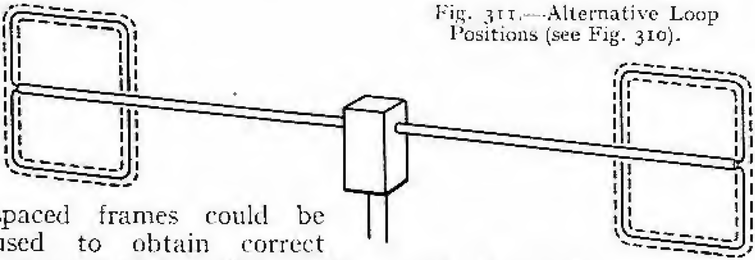


Fig. 311.—Alternative Loop Positions (see Fig. 310).

Trials with Fixed Spaced Frames. Preliminary tests with the fixed frame apparatus are described in (3503) in which the effects produced on the balance of the system by site obstructions are mentioned. This reference also includes a large number of observations on high angle pulse signals that are of great interest in connection with propagation phenomena, and also a comparison of the spaced-frame performance with that of the Adcock in these circumstances.

Rotating Spaced Frame System. The rotating system is

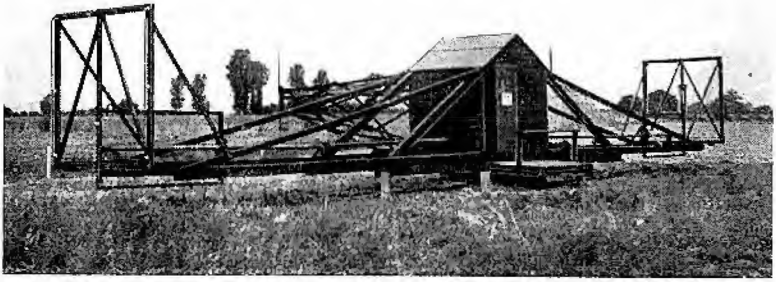


Fig. 312.—Eckersley-Marconi Rotating Spaced Frame Short-Wave D.F.

seen in Fig. 312 and the receiving apparatus in Fig. 313. Although a bearing can now be taken by rotating the aerials, the phase-balancing unit is retained, owing to the impossibility

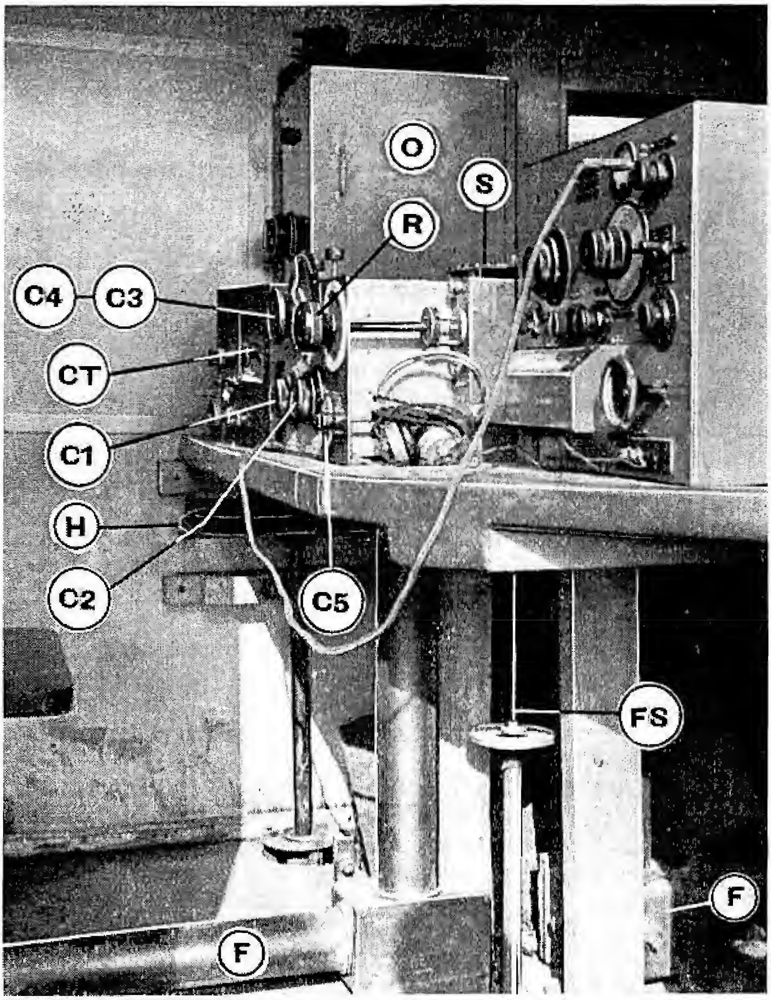


Fig. 313.—Receiving Apparatus in Hut of Fig. 312.
H. Hand wheel for Rotating Hut and Aerial System.
O. Local Oscillator for Setting-up.
FS. Fixed Spindle supporting Scale S.
CT. Cathode Ray Tube.
FF. Concentric Tubular Feeders to Frames.
(For remaining components see text).

of taking rapid swing bearings with such a heavy structure. The bearing is thus read off as the sum of the rotation and the additional phase displacement necessary for balance.

If θ be the angle between the direction of the transmitter and the line perpendicular to the connecting feeders, then so long as θ is not more than a few degrees, the spacing of the frames in the path of the wave, which is equal to $d \sin \theta$, may be written as $d\theta$ and the angular mis-phasing as $\frac{2\pi}{\lambda} d\,\theta$.

If ϕ be the phase displacement in the circuit to produce the balance, then $\phi = \frac{2\pi}{\lambda} d\,\theta$ and ϕ is proportional to θ.

The angle of rotation is measured on a scale fixed to a vertical central spindle, which is mounted on the foundation and projects through the apparatus table. The structure is mounted on a large diameter ball race and is turned by a suitably geared hand wheel in the hut.

Receiving Apparatus. Each screened aperiodic loop is coupled to an amplifier input circuit in which symmetry is carefully preserved as shown in Fig. 314. Either loop can also be isolated and earthed if it is desired to listen on one loop alone. C_1 and C_2 are the tuning condensers, whilst C_3 and C_4 are phase-balancing condensers mounted on a common shaft but arranged so that the capacity of one increases as that of the other decreases.

R is a radiogoniometer, the screened search coil of which is tuned to form the input to a commercial type of super-heterodyne short-wave receiver. The function of this radiogoniometer is to balance the amplitudes of the loop signals after the best phase balance has been obtained, the search coil rotation having no effect upon the phase relations of the two e.m.f.'s induced in it.

Lining Up. Having tuned in the required transmitter, it is first necessary to ensure that there is a correct phase balance, on this frequency, for a source of radiation along the XX axis. This is done by having a vertical dipole on an extension arm along this axis and which can be energized at the required frequency and then balanced out. This dipole may be seen in Fig. 312 to the right of the taller trees.

The calibration of the balancing condensers is obtained by having a second source of radiation at a distance from the receiving point, and by noting the movement of the pointer of the condenser scale necessary to get a balance for each degree of rotation of the frames up to, say, 5°.

Taking Bearings. With both the lining-up transmitters switched off, the loops are rotated until the required signal minimum is reached. The transmitter must be on the XX axis and not on the YY one, along which there will also be a minimum (page 221). Adjustments are then made with the phase-balancing condensers, and the search coil of the volume-balancing radiogoniometer is rotated to give a complete signal zero. The combined scale readings for rotation and phase balance then give the bearing correctly to ½° or ¼°.

The frames are now rotated through 180° to the reciprocal reading and a second bearing taken in the same way. Any discrepancy in the 180° difference between the two is due to the lining-up dipole not being exactly on the XX axis, and allowance can be made in the same way as for antenna effect in Fig. 71.

Signal indication is provided by both telephones and a cathode-ray tube, the latter having a linear time base.

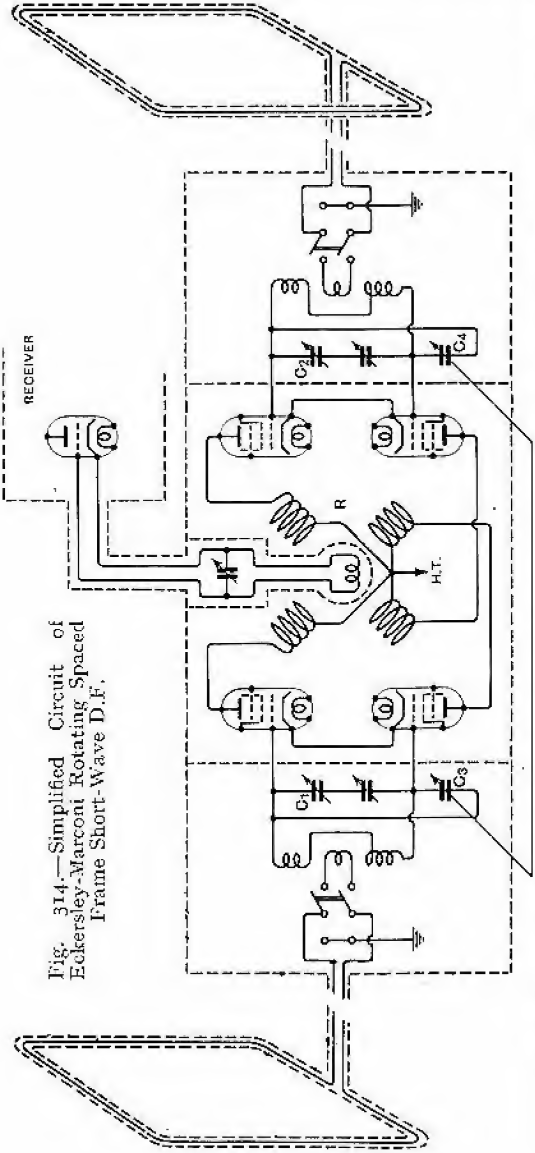


Fig. 314.—Simplified Circuit of Eckersley-Marconi Rotating Spaced Frame Short-Wave D.F.

In its present form the apparatus is essentially for research rather than commercial work, but it has the fundamental advantage over any form of Adcock array that it provides a good signal level together with accuracy on high angle as well as low angle rays.

THE MARCONI-ADCOCK DIRECTION FINDER TYPE D.F.G.12 (SHIELDED "U" TYPE AERIAL)

In the chapters dealing with the shore, marine and aircraft apparatus it has been found convenient to describe the general principles, the circuits and the details of apparatus first and to follow this where possible with commercial designs in a separate section. In the case of the short-wave Adcock system, however, the only commercial equipment on which design data is at present available is that of the Marconi Company and the technique of the shielded U type of aerial for commercial work on short waves has also been developed mainly in connection with this apparatus. Instead of attempting to generalize, therefore, the above installation will be described in some detail, digressing where necessary, to mention matters common to general short-wave work.

The equipment is designed for a wave range of 14 to 200 m.

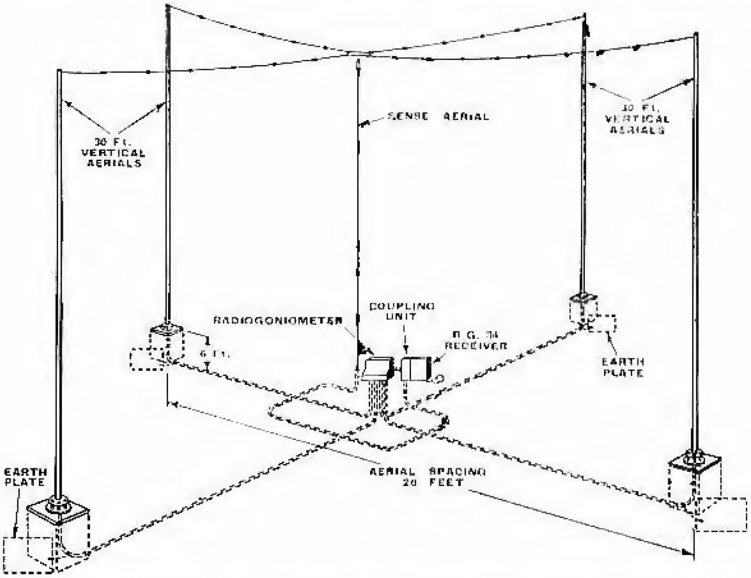


Fig. 315.—Mast Aerials and Feeders of Marconi Short-Wave Shielded "U" Adcock D.F., Type D.F.G. 12.

(21,400 to 1,500 kc.) and for use at any range where the angle of the reflected ray with the ground is not greater than 60°. It comprises a spaced aerial system, together with an auxiliary aerial for sense determination, a screened feeder system, two radiogoniometers with a change-over switch, a receiver and amplifier.

Aerial and Feeder System. Four 30-feet high, self-supporting galvanized steel masts provide the spaced aerial system and the auxiliary aerial is supported centrally from triatics of non-conducting material. The spacing is 20 feet (6·1 m.). The five aerials are connected to the receiver, which is located exactly at the centre of the system, by cable buried to a depth of 6 feet. This cable has been mentioned on page 311.

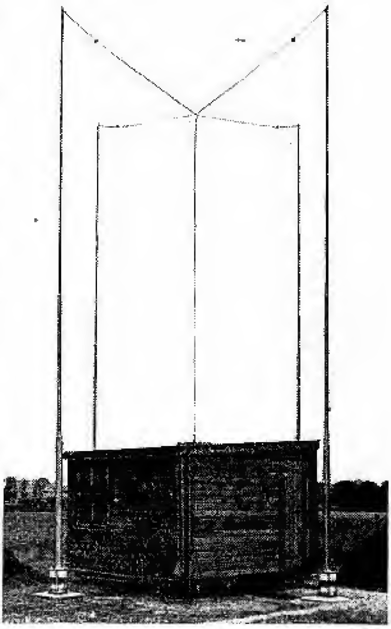


Fig. 316.—View of Installation of Fig. 315.

Fig. 315 and 316 show the general layout where the auxiliary aerial feeder is seen to be the same length as the other four, for reasons given later, the surplus length being suitably disposed under the receiving building.

If the soil conductivity be low, an extended earth at a depth of 6 feet is used, as in the medium wave shielded U Adcock, and is carried to a distance of 100 feet from the centre in the direction of the four aerials.

The feeder cable sheath and all other screening is bonded to the centre of the earth system, and earth plates are buried at intervals throughout its length. The object of the extended earth has been described on page 235.

As in all cases of B-T or Adcock aerials, there is some advantage to be gained by erecting the aerials accurately at the cardinal points of the compass, and this should be done when time and other factors allow of it, although it is not in any way essential.

Aerial Spacing. The reason for the octantal error due to small aerial spacing has been given on page 252 and due regard must be paid to this when preparing a calibration curve for use with the completed installation. On waves between 14 and 28 m., the normal angle of the incoming wave with the ground will be such that the curves shown in Fig. 226 can be used without undue discrepancies, provided that the process of calibration has shown them to be approximately correct. By this is meant that if bearings taken on known transmitters, or on aeroplanes or local mobile transmitters have confirmed that, say, the 16 and 18 m. correction curves of Fig. 226 give the proper value, it may be safely assumed that so far as aerial spacing error is concerned the intermediate 17 m. values may be interpolated.

Owing to the fact that the above D.F. works down to 14 m., and has a 6·1 m. spacing, a correction is required for all wave lengths below about 28 m.

Radiogoniometer Unit. This unit is seen on the left of Fig. 317, the left-hand radiogoniometer covering 14 to 60 m. (21,400 to 5,000 kc.) and that on the right, 60 to 200 m. (5,000 to 1,500 kc.). The change-over switch C also adds capacity in the search-coil circuit on the longer waves.

The aerial feeders are brought through the floor of the receiving hut in a straight line parallel to the back of the receiver, and suitable junction boxes are arranged so as to connect them to the receiver without any break in the screening.

Radiogoniometer Coupling Error. The method of arriving at the coupling error by measurement of the mutual inductance between field and search coil, as described on page 156, cannot be carried out in the case of short-wave radiogoniometers such as those used with the above apparatus. The inductance of the coils is of the order of 5 to 10 μhy., and test room methods of measuring, to an accuracy of 1 %, the mutual inductance of such coils with loose couplings and on frequencies up to 20 megacycles, are not available. Back-to-back methods also offer similar difficulties and a method has therefore been adopted which has the advantage of testing the radiogoniometer under working conditions.

To make the test, a rotating loop is mounted above the roof of the receiving hut of a short-wave shielded U Adcock layout, in a position exactly symmetrical with respect to the four aerials, the sense aerial being dismantled. Provided now that the receiver is adequately screened and the loop energized and rotated, the search coil should follow the loop, any discrepancy being due to coupling error. The aerial spacing error is not involved in this test but it is important that the loop should be small compared to the aerial spacing, otherwise it will itself have a coupling error introduced for the same reason.

Receiver. The receiver seen on the right hand of Fig. 317 is a superheterodyne with A.G.C. for telephony and telegraphy, but which can be switched out for direction finding. Plug-in coils are used for the input circuit from the search coil to the first amplifier valve, but the remainder of the R.F. amplifier and oscillator coils covering the five ranges are controlled by a range-switch E.

There are three tuning controls, the search-coil condenser B, the ganged R.F. amplifier circuits C and the oscillator F. The settings for the last two, for any frequency, are shown on the tuning scale D, which is changed automatically by the range switch. G is the frequency control of an oscillator giving a beat note with the intermediate frequency signal in case of C. W. reception.

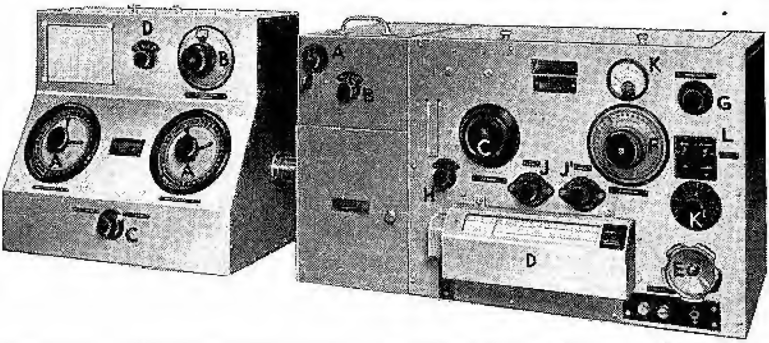


Fig. 317.—Receiving Equipment of Marconi Type D.F.G.12 Short-Wave Adcock D.F.

Radiogoniometers

A. Radiogoniometers.
B. Search Coil Tuning Condenser.
C. Radiogoniometer Change-over Switch.
D. Condenser Range Switch.

Receiver

A. " D.F.-Sense-Stand-by " Switch.
B. Search Coil Coupling.
C. H.F. Tuning Control.
D. Tuning Scale.
E. Wave-range Control.
F. H.F. Oscillator Control.
G. C.W. Beat Note Control.
H. Alternative I.F. Band Width Switch.
J J^1 L.F. and H.F. Gain Controls.
KK^1 Volt-Milliammeter and Meter Switch.
L. Auto-Gain and Beat Note Switches.

Sense Determination with the Short-Wave Adcock. It is found that if an attempt be made to obtain sense determination using a simple auxiliary aerial in conjunction with a shielded U aerial, over a range of wave length of 14 to 200 m., difficulty is experienced due to the widely differing characteristics of the two aerials and their possible modes of oscillation. With the spaced aerials connected to the receiver through deeply buried feeder tubes or cables, and the auxiliary aerial lead direct into the receiving building and coupled to an appropriate point in the receiving circuit, disconcerting reversals of relative phase between the aerial e.m.f.'s occur at various points in the tuning range with corresponding reversals in sense.

This can be improved by introducing the auxiliary aerial through a length of screened feeder identical with that carrying the spaced aerials, as shown in Fig. 315, the surplus feeder being coiled or doubled back. It is also necessary to pay particular attention to the balance between the halves of each individual " U " and between the two " U " systems.

A combination of inductive and capacitative coupling between the auxiliary aerial and the input circuit is another fertile source of trouble—even on medium wave lengths, and inductive coupling is used here with physical connection between the coils.

In order to avoid the natural period of the aerial plus field coil combination, and also to simplify the tuning of the search coil circuit on the longer wave lengths, two radiogoniometers are used and, mainly for the former reason, it is important to change over from one instrument to the other at the specified point in the range.

The danger of sense reversals on certain frequencies should always be borne in mind in the testing of a short-wave D.F. and particularly when an Adcock aerial is used. After the D.F. is in service, check readings can be taken on known stations from time to time in the course of routine testing, and this will immediately provide confirmation that all is in order.

Swing Bearings with Short Waves. On long and medium waves where fading is absent, or at any rate is very slow, it rarely, if ever, introduces any difficulty in the taking of swing bearings. Short-wave fading, on the other hand, may be extremely rapid and swing bearings must be carried out very quickly, and a number of swings may be necessary in order to arrive at an estimate of the mean value.

Probable Adcock Performance. The information tabulated below summarizes the results that may be expected with the Adcock equipment just described. This information must not be taken as rigidly correct under all circumstances ; it is quite impossible to cover all contingencies in a few words in this way. It does, however, give some sort of guide, provided that the optimum wave length has been chosen for the working range.

CONDITIONS OF RAY PROPAGATION	PROBABLE ACCURACY OF BEARINGS	PROBABLE D.F. RANGES
(1) Ground ray alone.	True bearings provided the transmitters and direction finding sites are free from local obstructions.	Distances between 15 and 30 miles on the shorter wave lengths to a maximum of about 100 miles on the longer wave lengths. Depends too much on conditions to express in few words.
(2) Ground ray and scattered rays.	True bearings when signal strength of ground ray is strong compared with that of the scattered and reflected rays.	
(3) Ground ray, scattered rays and high angle reflected rays.		
(4) Ground ray and high angle reflected rays.		
(5) High angle reflected rays only.	Bearings may be variable and unreliable. Variability depends on angle with ground up to 60°.	Distances between 30 and 200 miles on the medium and longer wave lengths of the short wave band.
(6) High angle reflected and scattered rays.		
(7) Scattered rays only.	No true bearings obtainable.	
(8) Medium and low angle reflected rays with and without scattered rays.	Good bearings generally obtainable but scattering may affect bearings when scatter ray comparable in strength with reflected ray and making appreciable angle with true direction.	Long distances obtainable.

Condition No. 5 is illustrated in Fig. 318 which shows a one hour record of variations in the apparent bearing of a 37·5 m. transmitter at a distance of 230 km., the angle of the reflected rays with the ground being between 70° and 75° and no ground ray being present.

Fig. 319 on the other hand is an example of the last mentioned condition No. 8 and represents the bearings of an aeroplane transmitter during a flight from Croydon to Cologne. The wave length was 53 m. and the bearings were taken from Chelmsford, Essex. The position of the aircraft throughout the test, shown by the curve, was obtained from the pilot's log and the maximum error at any time is 3°.

Ground ray conditions No. 1 are given in Fig. 320 (*a*).

CALIBRATION

Most of the suggestions regarding the calibration of medium- and long-wave ground D.F. stations given in Chapter 9, apply with equal force to short waves, and should be read in conjunction with the following further notes.

On completion of the installation it is usual to start by making a purely local check, using a transmitter at a distance of 100 to 200 m. or up to 400 m. if the site be reasonably clear. The transmitter should have a vertical aerial and be within visual range. It will not usually be possible to extend these tests to a 400 m. radius owing to obstructions, and particular care must be taken not to set up the transmitter near to any object that may possibly produce errors due to re-radiation, such errors being very misleading. An instance of a " source error " of this type is mentioned on page 398.

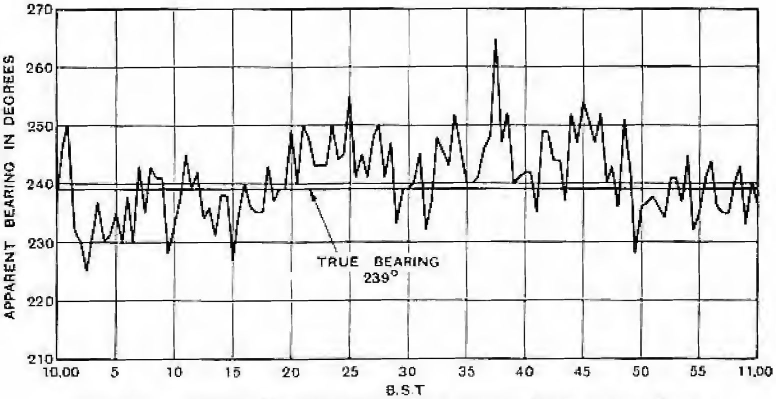


Fig. 318.—Adcock Bearing Variations due to High Angle Rays.

On completion of the local test, the radius of the transmitter may be extended to two or three miles, using an aerial of the " fishing rod " type on a motor van. Here the value of the results will largely depend upon the choice of the sites for the transmitter, and ensuring that it is always used in a clear space, and that obstructions between it and the receiving point are not extensive. In any case it is well to note carefully the details of the route between transmitter and D.F. from which satisfactory explanation for errors in certain directions may be found, if they should occur.

If, as is almost certain to be the case, the station is for work with aircraft, the whole of the wave range should later be covered in a series of tests at varying distances, using an

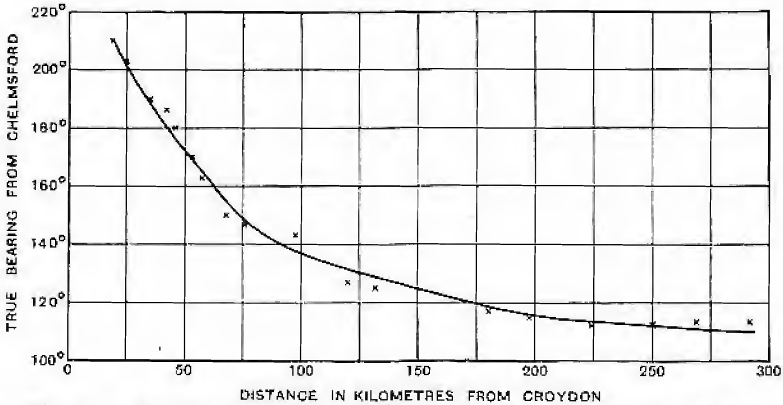


Fig. 319.—Improved Accuracy of Adcock Bearings with Low Angle Rays.

aeroplane with a vertical pole aerial. This, and the importance of making arrangments for the correct location of the aircraft as each bearing is taken, have been dealt with in Chapter 9. As in the case of long waves, it is an advantage to have tests with trailing aerials also for the purpose of checking the freedom of the installation from polarization errors.

The results of a calibration flight are shown in Fig. 320(*a*). The wave length was 70 m. and the range 50 km. so that the conditions were purely ground ray, the test being made in the daytime. Each point represents the average of four bearings taken with the aircraft flying in four directions over the same point as described on page 352. The aeroplane effect was actually negligible, the bearings in each direction of flight being the same within observational and instrumental error.

The site of the D.F. for which Fig. 320(*a*) is the error curve, was chosen with particular care and, so far as ground ray bearings are concerned, is a very good one. Only one error of 2° was logged and most of the bearings are accurate to

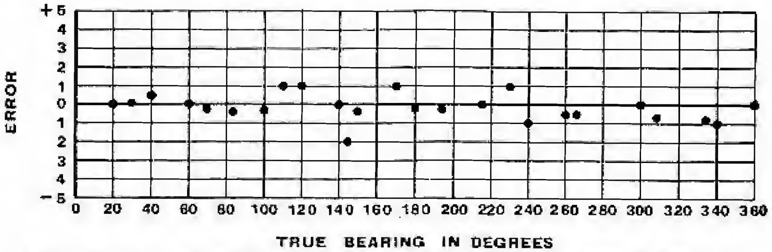


Fig. 320 (*a*).—Example of Short-Wave Adcock Calibration (see also next page).

within less than 1°. Fig. 320(*b*), on the other hand, is a correction curve for an island site, for which no alternative was available, and which had little in its favour. The layer of soil was so shallow that there was difficulty in burying the earth system and channels had to be hewn in the shale and rock to take the aerial feeders. The site was uneven and had buildings, wire fences and power wires within a wave length or two. In spite of this a good calibration was made over the required sector of 270° to 90° by means of some 350 bearings on aircraft at distances of 20 to 1,600 miles, ships at distances of 300 to 2,000 miles, a local transmitter with vertical aerial at 900 feet, and checks on fixed shore stations. The curve shows a marked octantal component due to radiogoniometer coupling error (compare Fig. 295), but the remaining discrepancies are surprisingly small in view of the nature of the site, and, being stable, have enabled the D.F. to give reliable service.

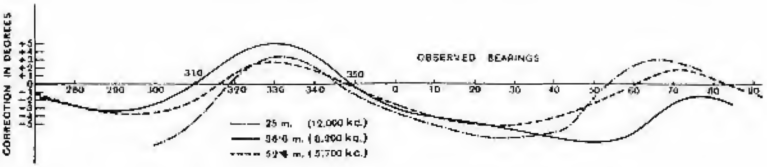


Fig. 320 (*b*).—Further Example of Short-Wave Adcock Calibration.

Calibration on Known Transmitting Stations. In the use of existing working transmitters, there is not only the difficulty of finding them on suitable wave lengths in the desired directions, but also the danger of being misled by bearings taken on scatter sources as already mentioned. There is, however, much useful information to be obtained in this way and, provided that the behaviour of the bearings of distant transmitters be watched for a time, it will become evident to what extent they may be relied upon for calibration purposes.

After the D.F. is in commission, check bearings on a set of distant transmitters will often provide data on freak propagation conditions, thus explaining apparent discrepancies in the bearings of mobile transmitters under observation.

Transmitting Aerial "Source Errors." Transmitting aerials supported by steel masts may also give entirely erroneous bearings at close range, and a case of this is mentioned by T. L. Eckersley (3606). In carrying out tests with a rotating, capacity screened, loop it was noticed that a T-shaped transmitting aerial, at a distance of 2·96 km. from the D.F., gave a bearing 10° in error on a 26 m. wave length and an indefinite minimum on 30 m. Using a transportable D.F. with screened loop, the 30 m. wave length again gave an indefinite bearing whilst the 26 m. bearing was now 18° in error.

The transmitting aerial was supported between two 121 feet high lattice steel masts separated by 156 feet, the aerial being a dipole, with the feeder wires connected together at the bottom of the down lead, and the aerial rigged as shown in Fig. 321 (*a*). When pulled to the opposite side as in Fig. 321 (*b*) the error was reduced to 3°, but in no intermediate position was it zero due, apparently, to the different electrical characteristics of the two masts.

An effect such as this can definitely be ascribed to a "source error" and it was presumably a polarization effect since the spaced frame D.F. described on page 384 not only gave a correct bearing but differentiated between the two positions of the aerial, which was a matter of only 0·2°.

An Adcock equipment of the type described above was also available, and the error in this case was also noted to be very small, but the above example shows the danger of using, for calibration purposes, any transmitting aerial other than a vertical wire situated well clear of all obstructions.

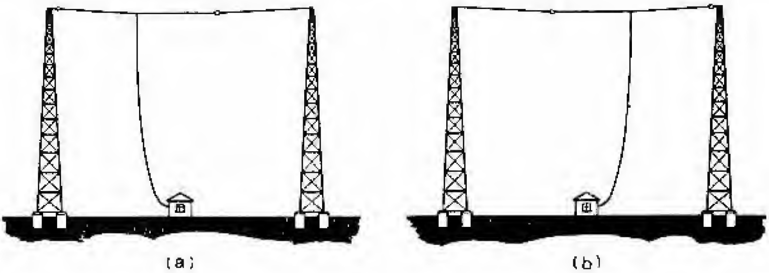

(a) (b)

Fig. 321.—"Source Error" of Transmitting Aerial.

CHAPTER 11

THE SHIP D.F. INSTALLATION

Shore versus Ship D.F. Installation. If any reminder be necessary of the importance of the present-day Marine D.F. installation as an aid to navigation, it may be found in the fact that the Board of Trade Regulations have, for some years, made it compulsory for passenger carrying British ships of 5,000 tons gross, and upwards, to have such gear fitted. The reasons for these regulations and for the increasing popularity of the D.F. in ships may be found among the points set out below, the principles involved in many of which apply with equal force to D.F. in aircraft.

(*a*) With the D.F. in the ship, a bearing may be taken of any shore transmitting station, light-ship or any other vessel; in other words, every wireless station becomes a beacon. It must be remembered, however, that whilst every shore D.F. station is carefully calibrated over the whole of its working sector, transmitting stations may, unknown to those responsible for them, have sectors in which their wave front or wave polarization is so distorted as to give inaccurate bearings (page 598).

(*b*) The ship's navigator may prefer to have the bearings taken by someone he knows and in whom he has confidence, rather than by persons who are not under his control. This applies more particularly to the periods when the ship is abroad.

(*c*) During thick weather, any number of ships are able to find their positions from a series of beacons or shore transmitting stations simultaneously, without any interference, whilst the shore D.F., with its associated transmitter, is working continuously in foggy weather, and is therefore causing and experiencing much jamming due to the large number of ships requesting bearings.

(*d*) During fog, the ship D.F. is valuable for preventing collisions (page 601).

(*e*) A ship in distress, whose wireless transmitter is still in working order, can be found in the shortest possible time by a ship with a D.F. Similarly a ship in distress having a D.F. can direct other ships what course to take to find her (page 601).

(f) In a ship, there should be very little chance of error, apart from the difficulty of getting first-class bearings during bad weather. In the case of bearings or positions transmitted to the ship from a shore station, there is always the possibility of a mistake in transmission or reception by W.T. and in some cases there is also a land line transmission from the shore D.F. station to the controlling transmitting station.

(*g*) In time of war, the ship D.F. has the advantage of being able to take bearings without betraying her position to enemy ships.

(*h*) The use of the ship's D.F. for directional reception and the elimination of interference greatly facilitates the handling of traffic in crowded areas.

(*j*) Insurance premiums on ships trading in certain parts of the world are reduced if a properly equipped D.F. is installed.

Wheel House or Wireless Office Location for the D.F. Until a few years ago the question as to whether the wheel house or the wireless office was the better location for the D.F. was a vexed one, and the latter site was commonly chosen. The present-day tendency is towards installation in the wheel house and some arguments for and against this change are enumerated below.

The Wheel House Site. Marine D.F. gear is now designed with a view to it being operated by deck officers, and bearings can be taken after a little practice by anyone in such capacity. It is very necessary, however, that the user should be sufficiently expert in morse reception to be able to identify the required transmitting station, even through bad interference.

Although an instrument of navigation, the D.F. is essentially wireless apparatus and must be under the constant supervision of the telegraphist if he is to be responsible for its efficient working. It is also an advantage that the telegraphist should have constant access to the D.F. in order to keep himself proficient and to give the officers the benefits of his experience in the work. He should, if available, be present and listening in a second pair of telephones when the D.F. is being used as a means of position finding in fog.

Some of the disadvantages of the arrangement are that in many ships the distance between the wireless office and the bridge may entail a walk for the telegraphist with a delay of a minute or two whenever a bearing has to be taken. During this time a listener must keep watch on the main receiver. Again, in some shipping lines, the presence of the telegraphist on the bridge is considered undesirable, and the conditions do not tend towards the co-operation that is so essential if the best results are to be had with the apparatus. A further complication of the wheel house site, though one that is easily surmounted, is that remotely controlled switches are necessary to ensure that, firstly, the main aerial is insulated when the D.F. is in operation and, secondly, that the D.F. apparatus is suitably protected when transmitting on the main aerial.

Wireless Office Site. The fundamental disadvantage of this location is that the gear is no longer under the eye of the navigator. The telegraphist can also no longer keep in direct communication with the helmsman, and either a telephone or a system of gong signals becomes necessary in order to synchronize the taking of a bearing and the reading of the steering compass. If a gyro-compass be installed in the ship, and a repeater dial in the wireless office, the conditions for accurate D.F. work are extremely favourable, but the gyro-compass is, at present, seldom fitted in merchant vessels.

The proximity of the down lead of the main aerial may be an obstacle to the erection of the rotating loop over the wireless office, but a moderate length of cable usually allows the B-T aerials to be placed far enough away to prevent bearings being thus affected.

A point greatly in favour of fitting the D.F. in the W.T. office is that its directional qualities may be of value in clearing traffic during periods of bad jamming.

As time goes on and the D.F. becomes more and more a regular instrument of navigation, it is almost bound to find its way more frequently to the wheel house. In this case, it is of the greatest importance that all deck officers should be skilled in its use. Our emergency may arise when the telegraphist has urgent work in the W/T office and when lack of skill in identifying a beacon transmitter, or a coast station call sign, or the inadvertant setting of a course towards the radio beacon of a light vessel (page 600), may lead to disaster.

The apparatus should in any case be of modern design, kept in first class order, and constantly used in fair and bad weather. Some further notes on the use of the D.F. appear later in the chapter under " Taking Bearings."

THE B-T AERIAL IN SHIPS

The methods adopted for rigging the B-T aerials on board ship have passed through several stages of development since the early use of D.F. in ships. Up to 1922 it was common practice to fit loops of the maximum possible area, these being rigged from jumper stays between masts or funnels, etc., and with the thwartship loop often the full beam of the vessel. Up to 1925 there was a tendency to reduce the size of the loops and to adopt a much more rigid mode of support, such as short, robust spars specially erected for the D.F. loops on the boat deck or other convenient space. Whilst the smaller loops resulted in reduced signal strength and needed higher amplification, it was easier to find a site for the aerials which was near the W.T. office and yet free from derricks, etc. Again, in 1926, there was a movement towards still smaller and multi-turn B-T frames, which are surrounded by an earth screen and may be enclosed in weatherproof casing.

Experience in many hundreds of ships had shown that it was often easier in practice to maintain a reasonable degree of accuracy by the use of the smaller fixed frames, in spite of certain advantages of the very large loops which are mentioned below.

In the meantime, the now familiar all-metal construction for use with the rotating frame system had been developed, and made an instant appeal to ship owners owing to its attractive lines and obvious weatherproof properties, and it was adapted for use with the B-T system. These B-T loops have been fitted in considerable numbers and although this metal screened design for the B-T system has shown signs of giving way again to unscreened loops of slightly larger dimensions, the space taken up is still negligible by comparison with the loops of 1920.

Owing to the valuable information that was gained during the use of the large B-T loops, and in view of the fact that they still have a useful field in H.M. ships and for other special purposes, it is considered worth while to devote some space to the early designs. By dealing with the matter historically, the points for and against the small loops become more clear, and as a result of the similarity in dimensions and design of the rotating loops and the present-day B-T loops, both can conveniently be considered together at the end of the section.

CHOICE OF SITE FOR AERIALS AND METHODS OF SUPPORT FOR LARGE B-T LOOPS

Although large B-T loops are being mentioned first, a great deal of what is said regarding the problem of finding a suitable site applies with equal force to the rotating loop D.F. The reader will have little difficulty in discerning which remarks are applicable to B-T only.

Large Loops. (Over 500 Square Feet). One of the chief advantages of the large loop is that is it less affected by individual structures in the ship which cause quadrature effect when using smaller loops and frames.

In selecting a suitable position for the aerials, the following important points should be borne in mind :

(1) The two frames must be rigged accurately fore and aft, and thwartship, respectively.

(2) The aerials should be rigged symmetrically with regard to the centre line of the ship, although this is less important with small multi-turn frames.

(3) The aerials should not interfere with or be interfered with by the rigging of the ship.

(4) The position selected for the aerial should be as near as possible to the position selected by the owners of the ship for the D.F. instruments.

(5) The aerials should, if possible, be rigged in a position which will not necessitate their being unshipped when in port.

(6) Each loop should be symmetrical about its central vertical axis.

The preliminary survey must usually be made whilst the ship is in port, and although under such conditions a better idea may be gained of the space required by the derricks, etc., it must be remembered that in certain cases essential steel wire stays are slacked off when working cargo. Occasions have arisen in which aerials have been rigged in apparently ideal positions in port and have been rendered useless later owing to a steel stay passing close to or even through the loops, producing electrical coupling between them or out of balance capacity to earth, with errors of 10° or more.

Electrical interference from motors is also difficult to judge when the ship is in port, and although a site be chosen where induction from derrick motors can be eliminated, a multitude of ventilating fan motors will probably be in operation when the ship is under way, or in the tropics, and may give endless trouble.

With regard to electrical interference it may be mentioned that dirty commutators on cabin fan motors are a fertile source of trouble.

When the aerials are rigged on a boat deck, the aerial stays must not interfere with the working of the boat davits, and due consideration must be given to the subject of head room and the possibility of deck cargo. The aerials should always be out of reach of passengers and should not encroach on passengers' deck space ; furthermore, no part of the installation should be placed in a position which is considered unsightly when alternatives are available.

It will therefore be seen to be advisable to have a consultation with someone in authority in the ship before making any decisions and, when possible, all electrical apparatus should be put into operation for the purpose of testing, on a temporary aerial, the extent to which electrical screening of power leads, etc., will be necessary.

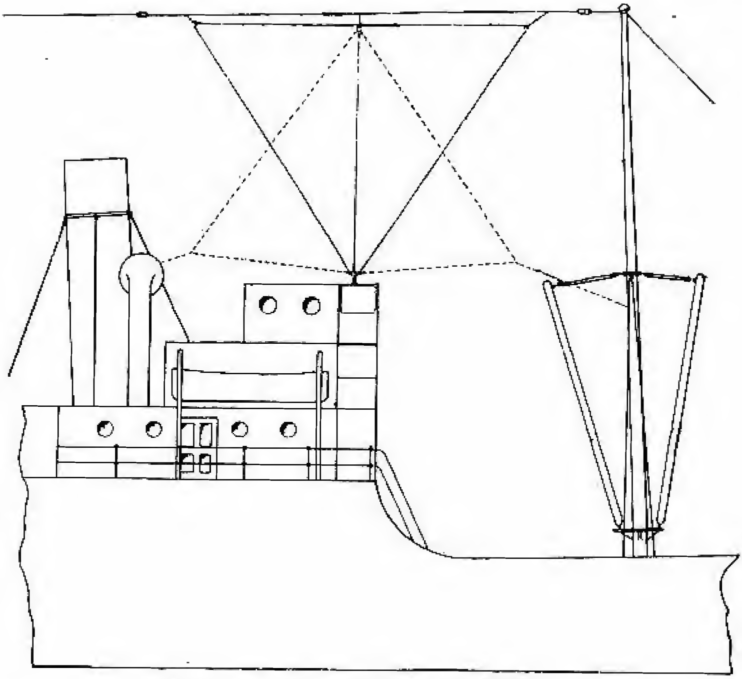


Fig. 322.—Inverted Fore and Aft Loop.

The problem of finding a site for loops of 500 square feet or more becomes a serious one at times, and particularly in a small vessel such as the one shown diagrammatically in Fig. 322. Suppose that in this case the W.T. office is forward and the only clear space for the aerial is over the bridge. The rigging of the thwartship aerial is comparatively easy ; a jumper stay to support the apex and the lower corners stayed out to the bridge wing shelters. If now the fore and aft loop be supported from the same point, as shown dotted, it will be necessary to stay out to the mast and this fore stay will foul the derricks. A method of overcoming the difficulty is to invert the fore and aft loop as shown in the figure.

An alternative solution is given in Fig. 323, in which the loops are separated, enabling the fore and aft loop to be stayed out to a bridge awning spar, whilst the thwartship loop remains in the same position as before. This arrangement may be necessary to clear signal halyards and an example of it exists in Fig. 329.

Merchant or passenger vessels having two funnels will usually be large enough for sites to be found for the loops which are comparatively clear. On the other hand, in the case of a warship, say a small cruiser, the greatest difficulty may be found in selecting an approved site. Fig. 324 shows an arrangement which has been used successfully, consisting of a rectangular loop between the funnels and a triangular thwartship loop supported from a jumper stay between the masts. In such a case the fore and aft loop will probably have to be made very much smaller than the other, but the calibration of such a system may, nevertheless, be quite straightforward.

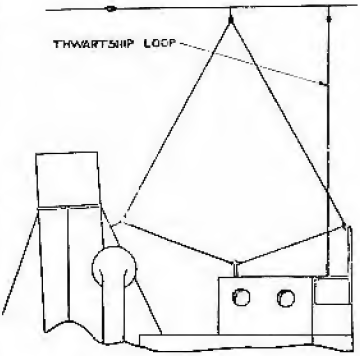


Fig. 323.—Separated Loops.

In general it is found that the best sites are amidships, with good symmetry both fore and aft and athwartships.

Quadrature Effect. Under the heading of " Re-radiation or Quadrature Effect " on page 89, it was explained that the electromagnetic field in the neighbourhood of a ship's D.F. aerial is generally an elliptical one, in which even the major axis does not indicate the true direction of the incoming wave. The ellipticity, and hence the indefinite cosine minima, were due to a component of re-radiation from surrounding metal work, with quadrature phase relationship to the main field, whilst the main field itself is distorted due to the large metallic mass of the ship and is dealt with later under " Quadrantal Error " (page 431).

There are various fairly straightforward methods of correcting quadrantal error, but quadrature, if serious, may render the apparatus unnecessarily tedious to use and also less accurate, and it is thus important to be able to recognize surroundings likely to produce the latter effect and to avoid them, even at the cost of increased quadrantal error if necessary.

Some Causes of Quadrature Effect. In general, the re-radiation is due to metallic masses near the aerials, which may include ventilators, masts, water tanks, funnels, derricks, davits for the ship's boats, rails, engine-room casings, etc., whilst steel wire ropes are particularly dangerous in this respect.

In case there is any doubt about the earth connection of a metal structure near the loops, this should be inspected and a good connection made, which will at least prevent the error from being an intermittent one. Where possible the cause of the trouble should be removed, but since this is rarely practicable, the only alternative is to rig the loops as far away as possible and to use as large loops as possible, it having already been pointed out that large loops are less affected by any one individual metallic mass than are small ones.

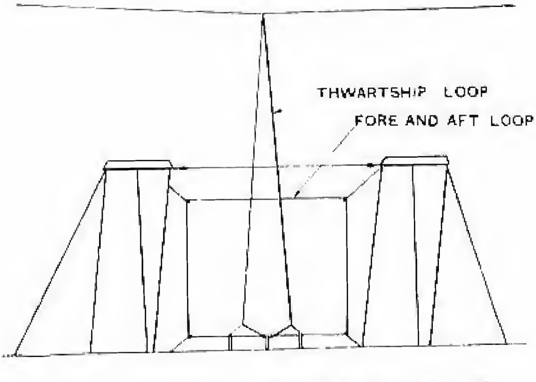


Fig. 324.—Fore and Aft Loop Between Funnels.

This was, in fact, one of the alleged advantages of large B-T loops which could often be used with no zero-cleaning device whatever ; though in view of the simplicity of the operation and its almost universal acceptance now as a part of the tuning, the argument is not a very strong one.

Steel wires such as whistle lanyards or the jack stays supporting them should be broken at intervals by means of porcelain insulators if they pass near to the aerials, and this also applies to jumper stays. If possible no metal should come within six feet of the loops.

Serious errors are sometimes caused by induction from closed loops formed by the ship's rigging. A case is on record in which the "loop" consisted of the funnel, a stay from the top of the funnel to the fore-mast, shrouds and the steel deck. In fair weather no ill effects were noticed, but during wet weather or when spray was flying, the serving under the thimbles of the steel ropes became conducting and this loop caused violent distortion of bearings. In certain instances bearings which should have been on the starboard bow were made to appear on the port bow. This very dangerous form of error, in which bearings appear in the wrong quadrant, is also caused by "lack of symmetry," and is referred to later in this chapter.

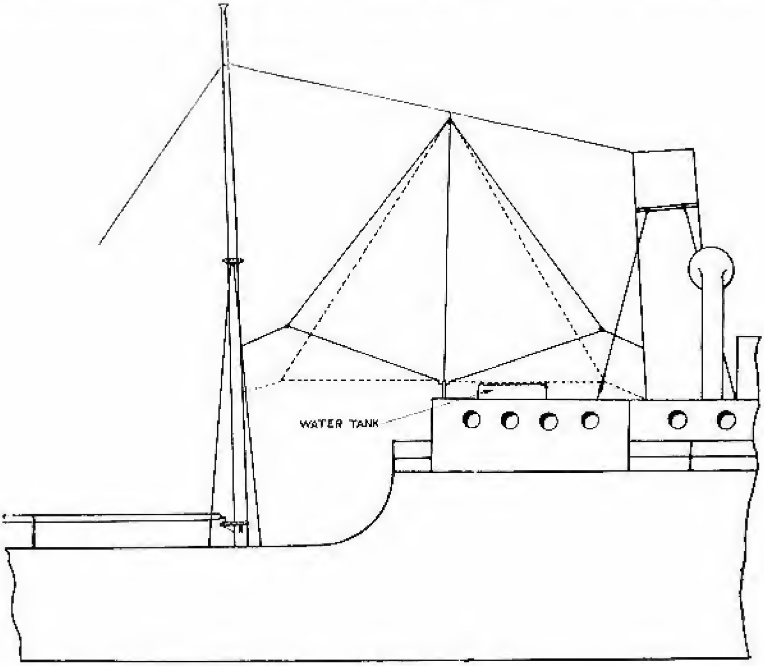


Fig. 325.—Diamond Shaped Loop to Avoid Capacity Unbalance.

The remedy in the above case consisted in having strop insulators of the form shown in the triatic of Fig. 262, spliced into one or more of the stays forming the loop.

Fig. 325 shows loops situated so that if the lower limb of the fore and aft aerial be horizontal, one half will run immediately above a water tank, whilst the other half is free of all obstructions. In order to avoid out of balance capacity and lack of symmetry error (page 424), it is advisable to have a diamond-shaped loop as shown by the full lines in the figure. The same trouble has been known to occur owing to an awning being erected under one limb of an aerial and the errors were found to be variable depending on whether the awning was wet or dry, and again the elevation of the outer ends of the loops cleared the fault.

Earth Screened Loops. In cases where the elevation of the outer corners of the loop does not eliminate the error due to stray capacities, an earth screen may be fitted consisting of one or two wires stretched about two feet below and parallel to the lower limbs and connected to earth. If the loops are small enough a screen may be erected round them in somewhat the same way as that used for the small fixed frames shown in Fig. 334. It must be remembered, however, that a capacity screen will only cure errors due to capacity effects, and that if the trouble is due to induction (*i.e.*, magnetic effects) from spurious loops, etc., the screen will probably be of no help.

Methods of Supporting Loops. Upper Support. There is rarely any difficulty in finding a means of support for the apexes of the loops, as jumper stays are frequently found in convenient positions between mast and funnel or between masts. It will be necessary to insulate any such stay at several points along its length, so that no one stretch is more than about 50 feet, unless (as mentioned on page 439) it is intended to use the distortion of

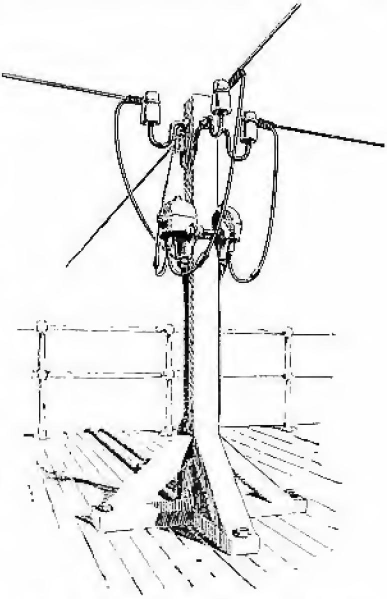


Fig. 326.—Aerial Lower Centre Support, showing Junction Boxes for Leading-in Cables.

bearings which results when the jumper stay forms a part of a closed metallic loop, as in the case when it is between funnels. If the stay is short, a comparatively rigid support can be obtained, but if it is more than 70 feet in length there will usually be some sway.

Lower Support. Fig. 326 shows a centre support designed for the case of aerials having a common vertical axis, the wooden pillar being fitted with four telegraph insulators on the usual swan-neck spindles to take the strain of the lower limbs of the loops. Immediately below them are the junction boxes.

Outer Supports. As a means of attachment of the stays from the lower extremities of the loops, awning stancions, bridge wing shelters, rails, etc., can be used with the permission of the authorities. In cases where convenient anchorage is not available, spars may sometimes be run out horizontally from the roofs of deck-houses, which will also allow of a thwartship aerial of the required dimensions being rigged in a vessel of rather small beam.

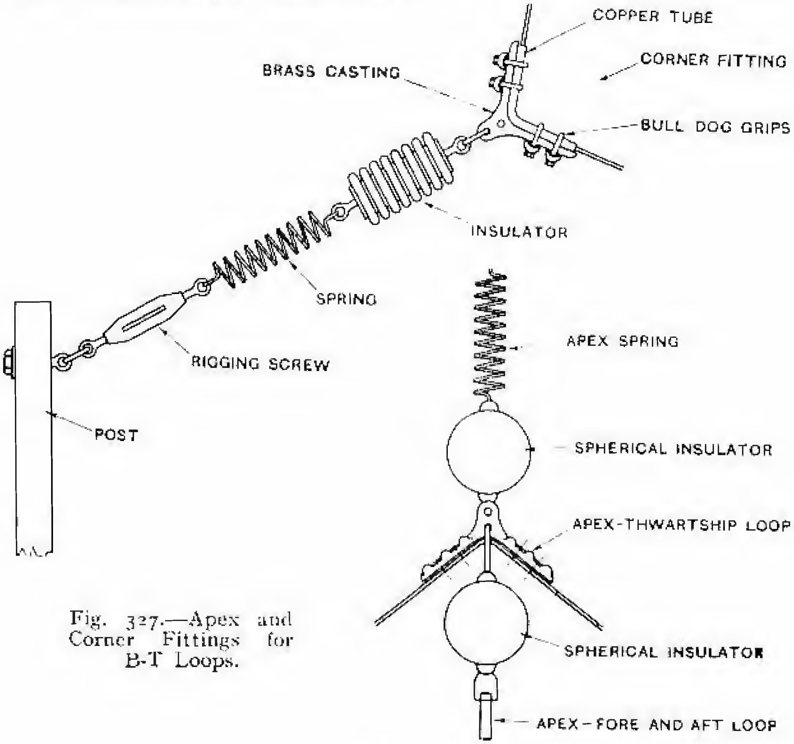


Fig. 327.—Apex and Corner Fittings for B-T Loops.

The staying of the fore and aft loop, in the case in which the aerials are rigged over the bridge, has already been mentioned, but when the arrangements shown in Fig. 322 and Fig. 323 are neither of them possible, the final alternative nearly always remains of bringing a stay to the fore mast and if this is liable to foul derricks it may be secured in such a way that it can be easily cast adrift when the ship is working the holds. The stay may alternatively be attached to a special spar on the lines suggested for the thwartship loop. Full sanction must be obtained for all structural alterations, however slight, and the standard of work done should conform to ship practice, and be as sound as possible.

Construction and Insulation of the Aerials. The loops are made of stranded silicon bronze wire, about 7/19 or 7/22 in size, free from joints and kinks.

Examples of various fittings that were designed for use with these large loops are shown in Fig. 327.

When made, the thwartship loop may be permanently rigged, but the fore and aft loop will probably have to be altered in size during calibration (page 432) and the rigging need not be finished off, so long as it is secure. As a first approximation, the fore and aft loop may be made about four-fifths the area of the thwartship loop.

Fig. 328 shows a general view of a vessel fitted with large loops. The photograph is taken looking aft, and shows the aerials rigged over the boat deck awning support. The cable junction boxes can be distinguished on the centre support and on the starboard side one of the vertical spars can be seen which supports the corner of the thwartship loop. The fore and aft loop has been kept clear of the awning by making it diamond-shaped. The apex insulator is supported from a jumper stay.

Reference has already been made (page 406) to Fig. 329 in which case the fore and aft loop has also been moved aft from the centre line of the thwartship loop in order to leave a clear space for the signal halyards, which can be seen in the photograph.

Medium Sized Loops (250 to 400 Square Feet). Owing to the extreme difficulty of finding, in some ships, a site which is sufficiently clear to rig large loops, near enough to the wireless cabin, and in which it will not be necessary to unship part or all of the aerial in port, recourse may be had to loops of between 250 and 400 square feet in area as seen in Fig. 330 and 331. These loops are preferably supported from five spars erected specially for the purpose ; one at each corner and a centre post at least six feet higher than the others. This ensures that the loops have a definite apex, which is an advantage in the ship B-T aerial system.

For much valuable data on the design and use of B-T installations with large aerials, in H.M. ships, reference should be made to a paper by C. E. Horton (3104).

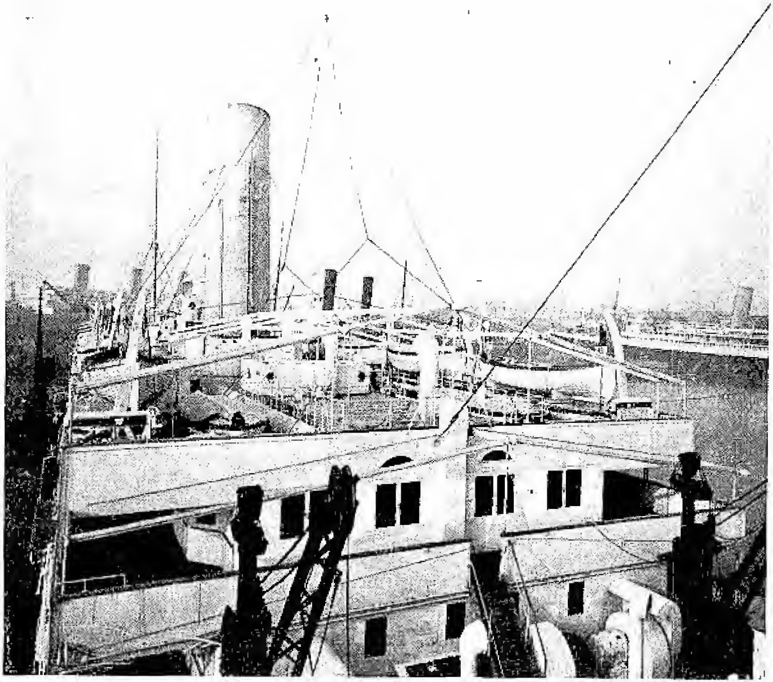


Fig. 328.—View of Vessel fitted with Large B-T Loops.

ROTATING FRAME AERIALS AND SMALL B-T LOOPS

From what has been said concerning the large and medium sized B-T loops, it will be clear that any advantages they may have had were bound eventually to be outweighed by their inconvenience in the average ship. The sacrifice of aerial pick-up, however, introduces the need of higher amplification and hence exaggerates the effect of stray non-directional pick-

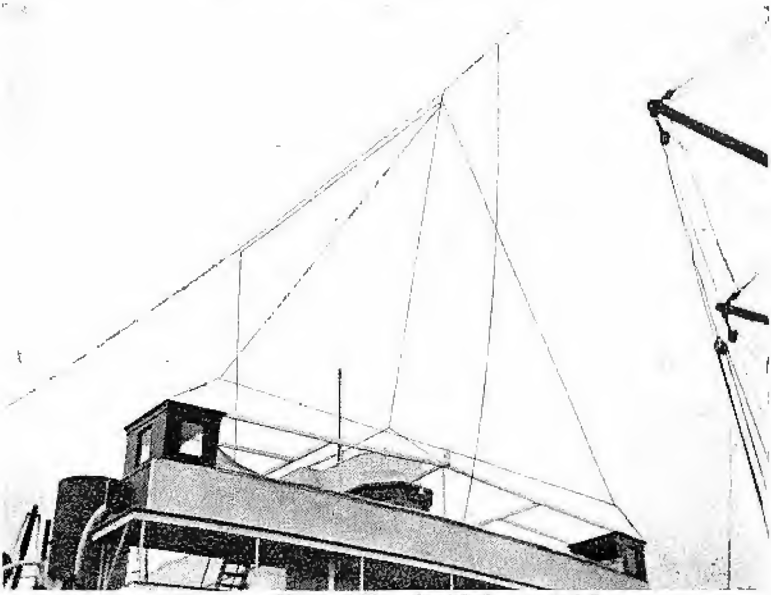


Fig. 329.—View of Vessel with Separated Loops.

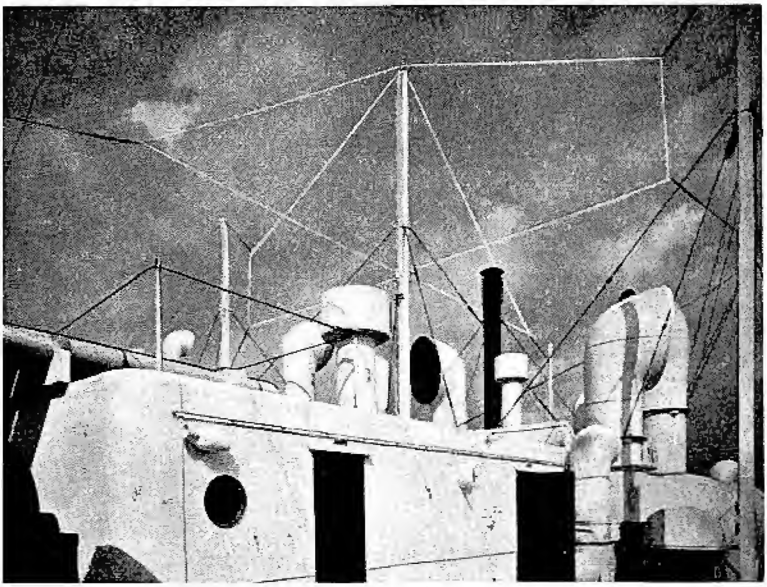


Fig. 330.—Vessel Fitted with Medium Sized B-T Loops.

up of signal, and also of electrical noise. It is for this reason that, as already mentioned, the larger loops are still used in certain cases in H.M. ships where the aerials—whatever their size—may have to be as much as 150 feet away from the receiving apparatus, and extreme accuracy and sensitivity could not be expected with small loops in such circumstances.

Radiation from steel stays, accidental closed loops caused by the ship's rigging and radiation from electrical machinery are liable to cause more trouble when using small loops, and

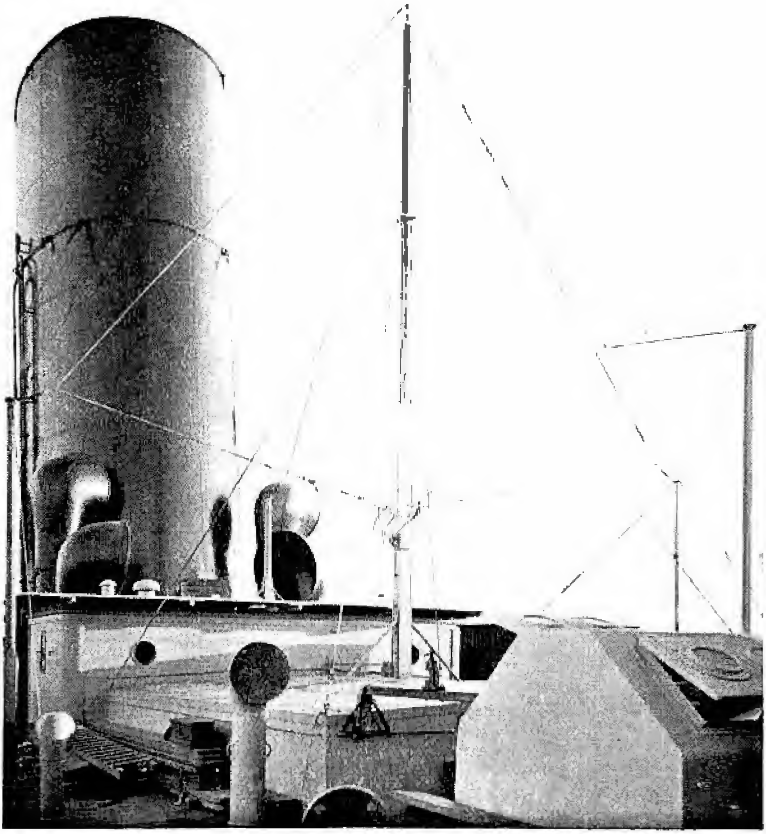


Fig. 331.—Vessel Fitted with Medium Sized B-T Loops.

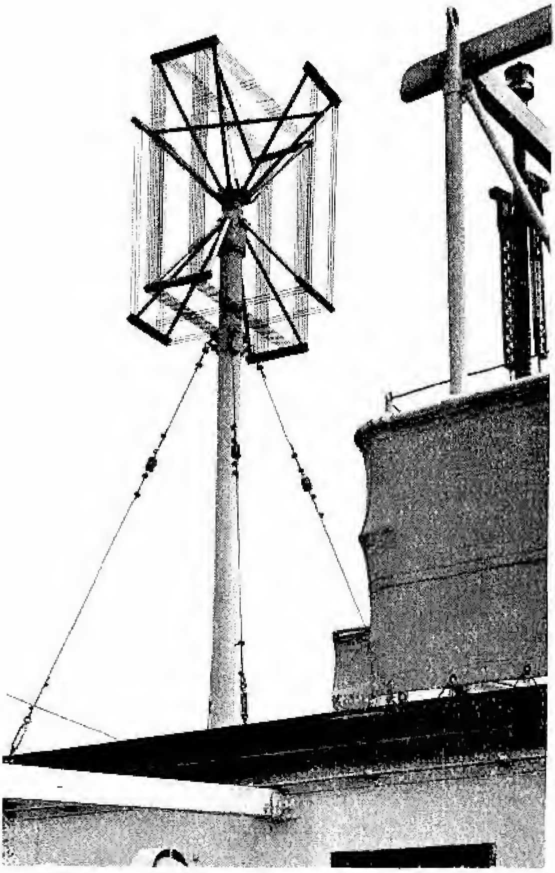


Fig. 332.—Robinson System installed in Ship.

advantage must be taken of the small size of the aerial fixture to place it in a clear situation, forward of the funnels if this can be arranged and also as high up as possible.

A further drawback of the rotating frame is that, as a rule, it will have to be mounted immediately over the wheelhouse or wireless office, regardless of the suitability of the site. To circumvent this, remotely controlled rotating loops are available, which avoid the compromise that must often otherwise be made between the most convenient position for the frame control and receiver, and the most practical site for the aerial loop. The loop shown in Fig. 337 can be arranged for remote control.

Two early forms of rotating frame are shown in Fig. 332 and 333, the former being in use about 1926 and employing the Robinson system (page 113) with main and auxiliary frame windings. The second is an American design of the conventional solenoid type of winding, which was in use before the design of small rotating loops swung over to the metal shielded type.

Capacity shielding of the small B-T loops was, for a time,

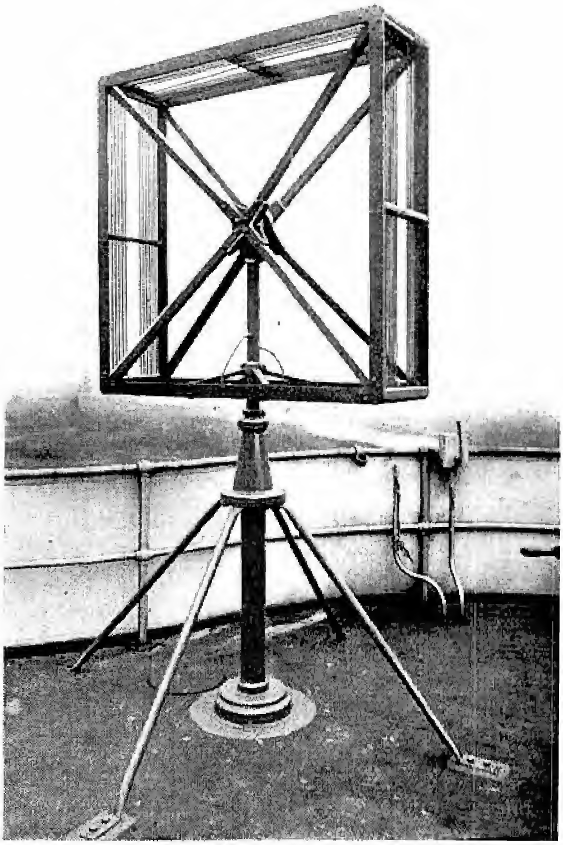


Fig. 333. Early Design of Solenoid Loop.

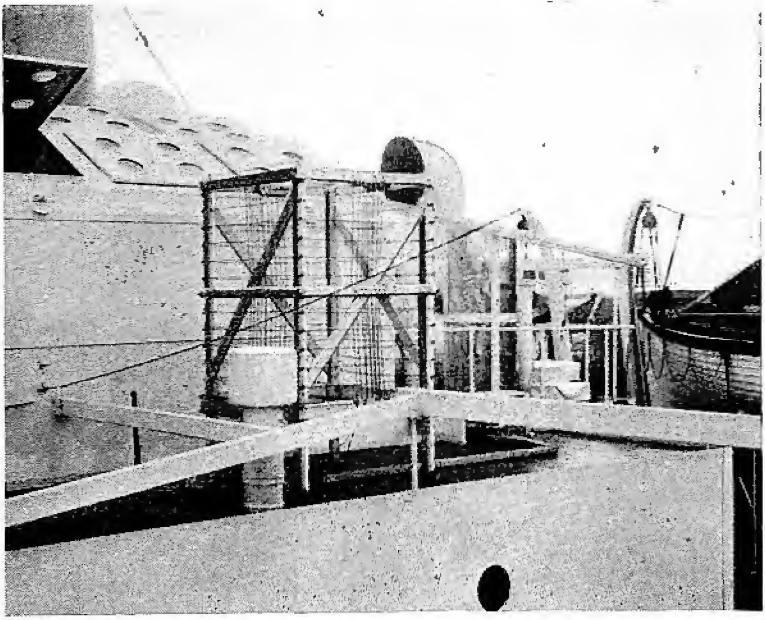


Fig. 334.—Small B-T Multi-Turn Frame Installation with Capacity Screen.

arranged as in Fig. 334, the screen being made of horizontal loops of copper wire, spaced 4½ inches apart and all bonded by a single vertical earthing strip. The screen loops were not in contact elsewhere with either metal or the wood framework. The aerial had 5 to 10 turns, depending on the type of radiogoniometer used.

A later design of unshielded B-T aerial is shown in Fig. 335, the loops being composed of pressure vulcanized, 4-core cable and having a diagonal dimension of about 7 feet. Reference is made again to this design below.

THE METAL SHIELDED SMALL LOOP

American and German ship D.F.'s have for many years used tubular metal shielding for their rotating loops, thus providing a capacity screen and at the same time a very efficient weather protection for the windings. It has also been adapted for use with B-T aerials.

Examples of the construction are shown in Fig. 336 to 339, and 401, and, whilst capacity screening is provided, it must be remembered that the screen is of no avail in the case of radiation effects due to local conductors, nor in the elimination of inductive coupling to neighbouring closed loops etc.

The shields are usually constructed of hard-drawn brass tube and are insulated at the supporting boss, or elsewhere in the circumference, so as not to form a closed loop and hence a short-circuited turn coupled to the winding. The losses traceable to the shield are extremely small if this precaution is taken, if the multi-turn windings are rigidly held in spacing washers, and the shield is connected to " earth." It is important in the case of the B-T construction shown in Fig. 338, that when assembling and installing, good contact is assured between the two shielding tubes and the clamp that holds them, and that this is in turn metallically connected to the base and to

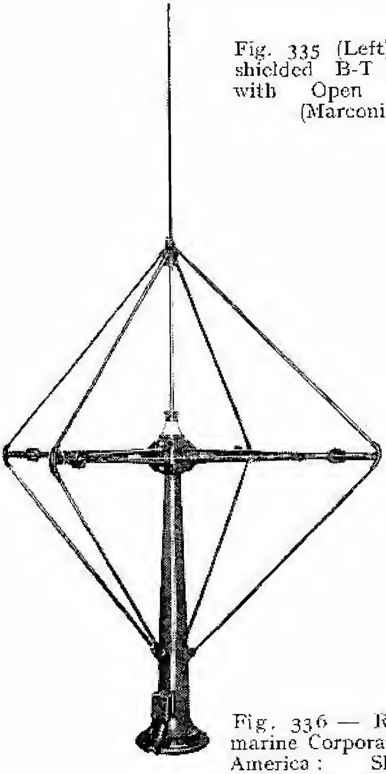


Fig. 335 (Left).—Unshielded B-T Loops, with Open Aerial. (Marconi)

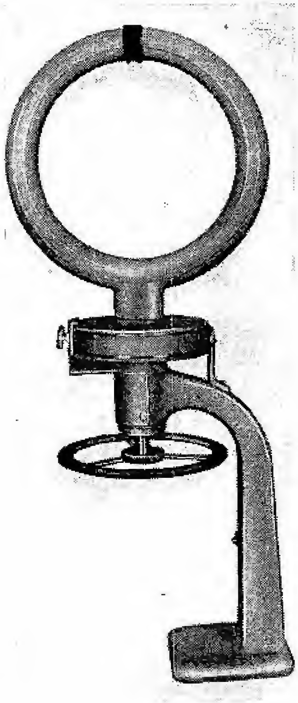
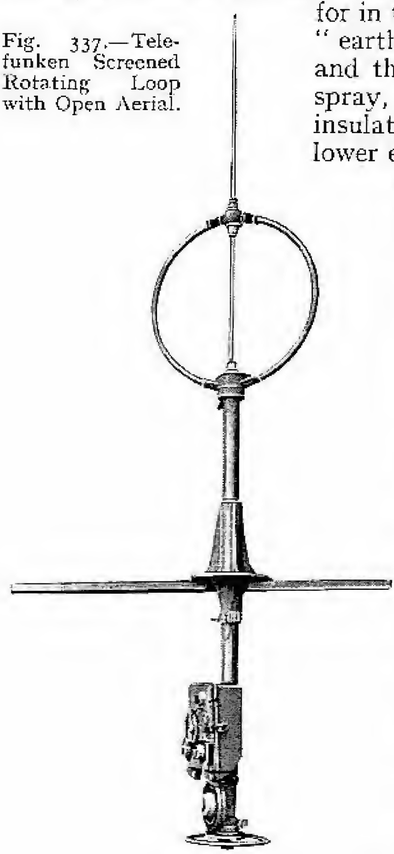


Fig. 336 — Radiomarine Corporation of America : Shielded Loop for Small Vessel Cabin Installation.

the cable sheaths. Some rather obscure troubles have arisen through lack of continuity in the bonding of the system.

It is an advantage if the discontinuity in the screen be arranged to be at the top of the ring, as in Fig. 337 and 339, for in this case the lower part may be "earthed" direct to the standard, and the accumulation of water from spray, etc., does not affect the insulation to the same extent. If the lower ends of the ring be insulated, a separate "earth" connection must be brought down from the top of the shield.

Fig. 337.—Telefunken Screened Rotating Loop with Open Aerial.



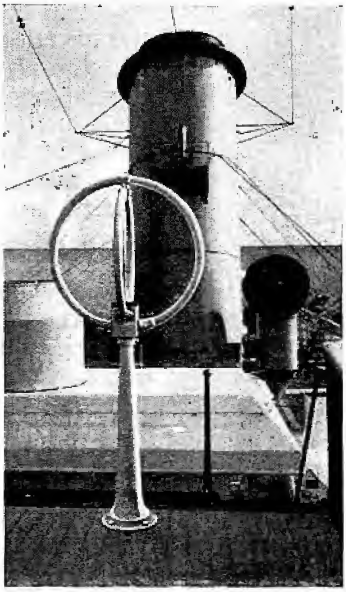


Fig. 338.—Screened B-T Loops (Marconi).

In addition to the tubes, it is usual to make the rest of the supporting standard of non-ferrous metal in order that the choice of the best position for the D.F. may not be hampered by the instructions regarding the placing of iron or steel structures within 14 feet of the magnetic compass.

It is advisable that the centre of gravity of these standards should be as low as possible, unless there is provision for staying them. Ships' decks are prone to a variety of types and periods of vibration and dangerous resonance may otherwise be set up.

The Radiomarine Corporation of America loop of Fig. 336 is intended for bench mounting in the all-wooden cabin of a small vessel, and particulars of these installations are given in (3703).

LEADING-IN OF THE AERIALS

The leads from a rotating frame will normally be carried down the hollow spindle which controls the movement and taken to the receiver through slip rings and brushes, in the case of the freely rotating spindle—as seen in Fig. 362, or through suitable flexible connections if the frame comes up against a stop after a rotation of some 500 degrees or so, as is sometimes the case.

For the remotely controlled rotating loop, or for B-T loops where anything up to 50 feet with small loops, or 150 feet with large ones, may separate the aerials and the receiver, the most convenient, and at the same time electrically efficient, lead-in is a lead-covered, paper-insulated twin-wire cable, constructed so as to have as small a capacity between the conductors as possible, the necessity for which is discussed below. By adopting telephone cable practice and using dry paper loosely packed for the purpose of keeping the wires in position, the dielectric becomes chiefly air and it is possible to construct a cable as shown in Fig. 340, the capacity of which is only 0·00086 micro-farad between wires, per 100 foot run.

The use of paper insulated cable introduces the need for junction boxes at either end, an example of the outer ones being shown in Fig. 335, where they can be distinguished at the base of the pedestal.

In selecting a position for the cables to be run, the shortest route should be chosen consistent with safety from mechanical damage. A number of faults have been traced in ship D.F. installations to the fact

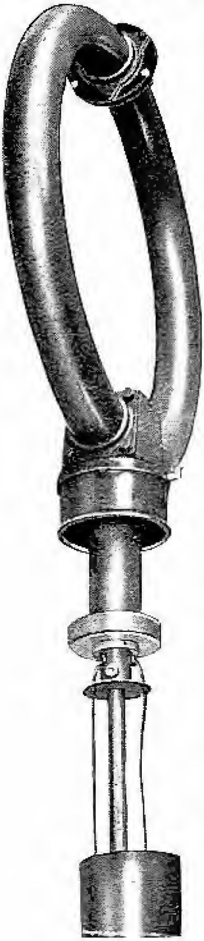


Fig. 339.—Screened Loop of Federal Telegraph Co.D.F.of Fig.361.

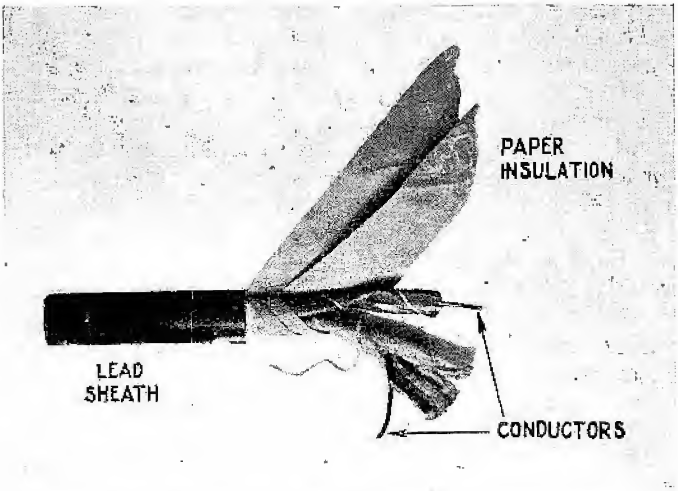


Fig. 340.—Lead-Covered, Paper Insulated Twin Cable for Leading-in. (About Half Size.)

that nails have been driven through the cables or the lead covering has been broken or chafed through. In addition to this obvious damage there is also the chance that the cable may be compressed, thereby causing a difference in the capacities of the two conductors to the lead sheath. This will introduce trouble due to asymmetry of the loop, and it is preferable to run the two cables together in a steel conduit, which must not, however, be brought within 14 feet of the magnetic compass.

LOOP TUNING ERROR

B-T Aerials. When the distance between the wireless office and the aerials makes it necessary to employ great lengths of leading-in cable, trouble arises owing to the natural wave length of the aerial circuit—which includes aerial loop, lead-in and radiogoniometer field coil—reaching a value which is within the range over which the set is designed to operate.

It must be remembered that in this case, the cables are a part of the aerial oscillatory circuit and are not transmission lines (page 167).

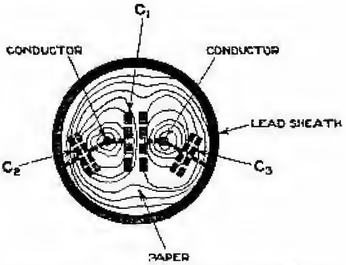


Fig. 341.—Self Capacity of Lead-Covered Twin Cable.

Fig. 341 shows, in diagrammatic form, the capacity of the two wires of the leading-in cable, and also the capacity of each wire to the lead sheath. These two capacities C_2 and C_3 in series are connected in parallel with C_1 and therefore increase the capacity of the loop. Not only may the natural period of either loop reach too high a value, but there is also the probability that since the loops are of different sizes, and are differently affected by adjacent structures, the natural periods of the two loops will not be the same. If by any chance the leading-in cables are not made the same length, the relative loop tunes will also be affected. The result is that when the aerial system is tuned to a wave length approaching the critical period for either loop, the amplitudes of the currents will no longer be directly proportional to the loop e.m.f.'s, but will depend also upon how nearly the loops are to the tuned condition. Bearings will thus be distorted and changes in the relative phases of the loop currents will cause indefinite minima.

In order to be on the safe side, the loop wave length should not exceed four-fifths the minimum wave length it is required to receive. With medium-sized single turn loops, lengths of leading-in cable up to 150 feet have been successfully used on wave lengths as low as 600 m., but this is a far longer cable than is advisable, and distances between aerial and W.T. cabin of 20 to 50 feet are more usual.

Test for Loop Tuning. The natural period of the thwartship loop—which will be the higher of the two—can be found in the following way. Excite the loop by means of a buzzer and battery connected across the appropriate pair of aerial terminals on the radiogoniometer, and see that the pointer is set at 90°-270°, which means that the search coil is at minimum coupling with the thwartship field coil and aerial. Now, using a wave-meter and telephones, observe the wave length of the radiation from the loop, which will be the loop tune.

Artificial Increase of Loop Tune Wave Length. If it should be wished to work down to wave lengths below 300 m. on an aerial system which must, at the same time, give reasonably good results up to above 1,000 m., it may be found impossible to avoid running into the loop tune of the thwartship loop. In these circumstances it may be arranged that when changing to the lowest wave range of the receiver, condensers are automatically connected across the loop terminals, thus placing the wave length for resonance up in one of the higher ranges. It will still be necessary to ensure that a ratio of at least 4 : 5 exists between the top working wave length and the natural wave length.

As a result of this alteration, the calibration will probably be affected and precautions must be taken to see that this point is covered by suitable instructions.

Another complication is that, since the working wave length of the loop is now below the natural wave length, there will be a lagging current at the point of cardioid minimum, instead of the more usual leading one, and this will reverse the direction of the sense, for which due allowance must be made (page 120).

Loop Tuning and the Rotating Loop. Owing to the limited distance between the aerial and the receiver, even with remote control of a rotating loop, the capacity of the cable rarely introduces any difficulty. In the Telefunken Ship D.F. described on page 448, however, it will be found that special precautions are taken to see that varying lengths of cable shall not upset the ganging of the receiver tuning control.

Aerial Transformers. In installations where very long cables are unavoidable, loop tuning can be evaded by the insertion of tightly coupled ratio transformers in the aerial circuit, at the junctions of the loops and the cables, as shown in Fig. 342. By using transformers having a ratio of 5 : 1, the high inductance winding being in series with the loop, the natural wave length of a large loop aerial with 100 feet of cable can be reduced from 500 m. to just over 200 m. Owing to the low inductance of the secondary windings of the transformers, it is necessary to have low inductance field coil windings on the radiogoniometers; but the decrease in the number of turns allows stranded wire, of larger overall section, to be used, and the reduction in the losses in the windings compensates for those introduced by the transformers. Note, once again, that the cables in Fig. 342 are still a part of the

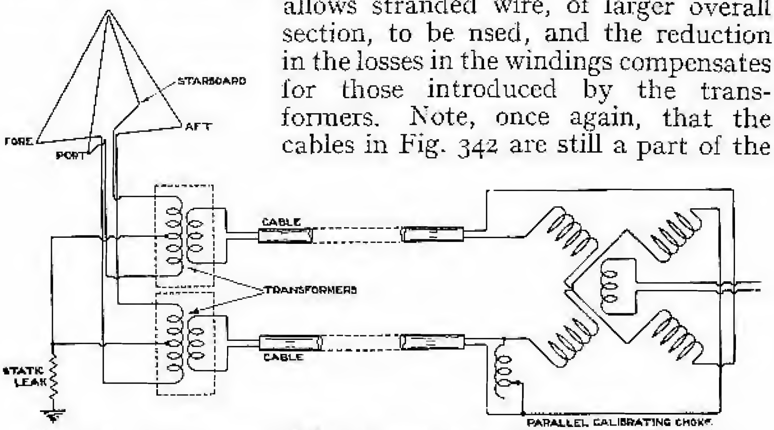


Fig. 342.—Arrangement of Ratio Transformers in Aerial and Lead-in.

aerial and field coil oscillatory circuit, and should not be confused with the transmission lines shown in Fig. 163. These ratio transformers are not in general use, now that the small fixed frames with a short lead-in have largely replaced the large loops with extremely long cables.

LACK OF SYMMETRY ERROR IN B-T INSTALLATION

A type of error to which the above name has been given may occur in any B-T installation, but is perhaps more common in ships, and particularly in the case of large or medium sized B-T aerials. It is unlikely to be encountered in the small frames unless a fault has occurred. It shows up as a warping of all bearings towards a certain point on the scale of the radiogoniometer which coincides always with the plane of one of the field coils. Note that it is not like the quadrantal error in which bearings are warped towards two diametrically opposite points on the scale. The distortion may vary from a small amount with or without indefinite minima, to the extreme case in which all bearings are apparently in the same direction and sense.

When the lead-in from loop to D.F. instrument is very short, we have seen that it is usual to connect the mid-point of the field coils direct to earth for figure eight reception in order to protect the aerials from static charges and also to eliminate antenna effect. Now, provided that the loops are electrically symmetrical, the earthed mid-point of the field coils should take care of any antenna effect ; but in practice it is very rarely that the B-T loops are rigged under such ideal conditions as to be free from some degree of out-of-balance capacity of the type which would occur, say, in Fig. 325. Similarly, the cables may not be well balanced, and the capacity C_2, Fig. 341, may not be the same as that of the other wire C_3. Owing to out-of-balance capacity effects, either between a limb of a large loop and a deck house, or due to a faulty cable or other similar causes, the distribution of the potential in the loop, when it is oscillating as an open aerial, is unsymmetrical and the electrical mid-point of the field coils is also no longer at the point where the tapping is made. Under these conditions the two currents through the two halves of the field coils are unequal, and an error is introduced which is extremely serious in that bearings may be made to appear in the wrong quadrant.

In Fig. 343, let O be the earthed mid-point of a radiogoniometer, F_f and F_a the two halves of a field coil and F and A the leads to the corresponding loop. Similarly S and P are the second loop with its associated field coils. If X O represents diagrammatically the direction of an incident wave, then it has been seen in Chapter 5 that the two currents I_{fa} and I_{sp} in the corresponding aerial circuits will be in the ratio sin θ to cos θ and the resultant flux in the field coil system will indicate the direction of the incident wave on the aerial system. From Fig. 45, we saw that the effective loop e.m.f. was the differential effect of two much larger e.m.f.'s in the side members of the loop, and that it was these which produced antenna effect. Thus, in Fig. 343, I_{fa} is the current due to the effective loop e.m.f. in the F A loop, whilst V_a and V_f are the two remaining antenna effects which, flowing in opposite directions through the field coil towards the mid-point, neutralise one another and produce no effect upon the search coil.

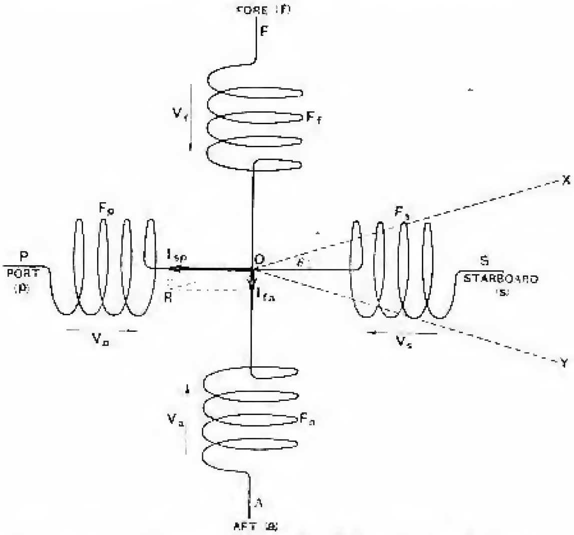


Fig. 343.—Theory of "Lack of Symmetry" Error.

Now suppose that due to one of the causes mentioned above the current due to the e.m.f. V_f in the F limb becomes very much larger than it should be. The current I_{fa} will be increased, and the position of the resultant R, and hence of the apparent bearing, will be distorted. If, on the other hand, a large stray capacity current flows in the limb A, the effective current I_{fa} will be reduced, and clearly, in certain circumstances, I_{fa} might be completely reversed, giving the bearing the appearance of being at O Y in the adjacent quadrant. Such an error in a ship D.F. may be a source of great danger when the apparatus is being used in fog for locating other ships. Since the e.m.f. due to antenna effect and the effective loop e.m.f. will normally be in quadrature, the minima will be correspondingly indefinite.

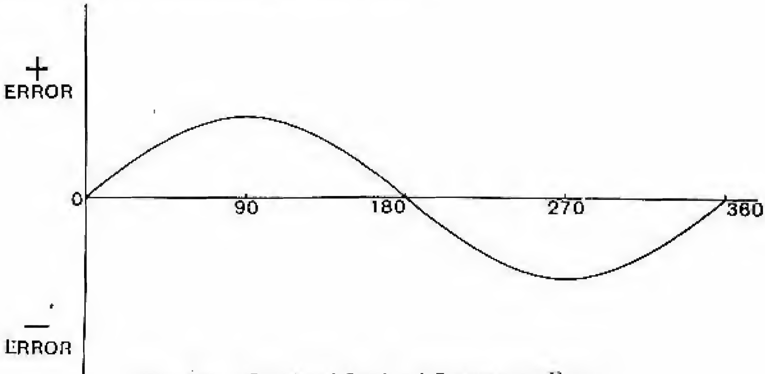


Fig. 344.—Graph of Lack of Symmetry Error.

In Fig. 344 the horizontal scale is that of a radiogoniometer, in which it is assumed that the axis of the F A field coils of Fig. 343 is along the 0°—180° line, and that of the S P coils along the 90°—270° line. If, now, the I_{fa} current becomes reduced from the cause mentioned above, this un-balance in the F and A coils will have the effect of making all the bearings from 0° to 180° too great and all those from 180° to 360° too small, and bearings will all be distorted towards the 180° direction as shown. If the I_{fa} current be too great, the error will be reversed and will be negative in the first two quadrants. In the same way, if abnormal currents flow in either limb of the S P loop, then I_{sp} will become either too large or too small and bearings will be distorted either to the 270° or 90° directions.

In very bad cases of lack of symmetry, all bearings may appear to be in one direction. In the other extreme, a very slight element of lack of symmetry may show up as a tendency for one of the minima on figure eight to be indefinite when signals are very strong ; the minimum becoming sharper when the amplification is reduced.

The Static Leak. Slight lack of symmetry which appears when there is a direct mid-point connection to earth in the radiogoniometer may be eliminated by inserting a H.F. choke in the earth connection, which acts as a leak for static charges on the aerial, but does not introduce this type of antenna effect owing to its detuning effect and the damping which is added to the open aerial circuit. This static leak is only included in the circuit when the figure eight diagram is in use. In cases where the field coil mid-point connection is used for obtaining the open aerial effect for sense determination, as in Fig. 137, the choke can be replaced by the requisite connection when switching over to " Sense." When aerial ratio transformers (page 423) are used, the choke is connected to the mid-point of the primaries and it becomes necessary to have a special aerial for the heart-shape circuit.

Test for Lack of Symmetry. Certain features in the design of the average radiogoniometer enable a critical test to be made for lack of symmetry, in a very simple manner. Suppose Fig. 345 to represent the plan view of a radiogoniometer in which F_f and F_a are two halves of one field coil and F_s and F_p the other. There is a mid-point connection to earth, and inserted in this lead is a small coupling coil to which is coupled a buzzer circuit. The instantaneous direction of the flux in the field coils due to the effect of the buzzer e.m.f. may be illustrated by the circles and arrows. Since the buzzer e.m.f. is applied at the mid-point of each field coil, the currents will flow from the mid-points to the aerials, and the fluxes in the halves of the coils will be in opposite directions and will tend to neutralize one another along the centre line of the coil corresponding to the 90° positions on the scale, *i.e.*,

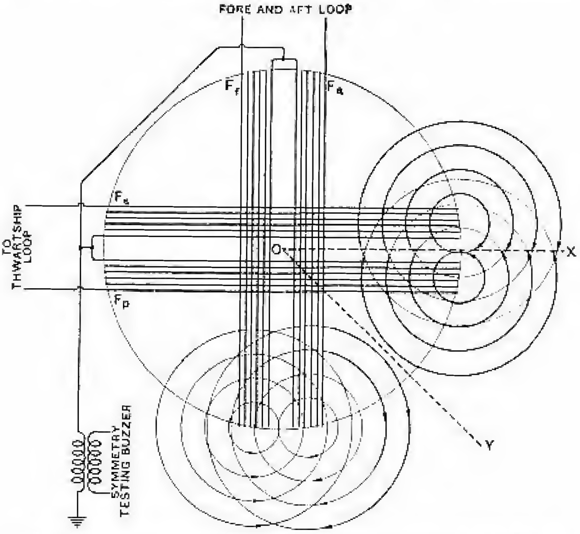


Fig. 345.—Principle of Test for Lack of Symmetry.

the 0°, 90°, 180° and 270° positions, one of which is shown by the dotted line O X. Similarly, at the 45° positions, as shown by O Y, there will also be a balance of flux and no linkage with the search coil, provided that the whole circuit is exactly symmetrical and the two loops are the same size. On trying other intermediate positions of the search coil, it will be found that the flux linkage always tends to cancel out, so that with the buzzer circuit used in this way, no sound should ever be heard in the telephones.

Now, the aerial system in a ship is never entirely symmetrical since the fore and aft loop or frame is always made to have less receiving power than the thwartship one. The result of this is that whilst the balance is still maintained at the 90° positions, when the symmetry test is applied, there will not be a balance at the 45° positions since the two opposite fluxes linking the search coil are not equal; the impedance, and hence the buzzer current, in the two aerials being different.

So long, therefore, as the symmetry of each individual loop is maintained, there will be no signal at the 90° positions, but if there is stray capacity coupling to earth from one limb of an aerial, or bad insulation or any other form of asymmetry, then clearly the buzzer current in the two halves will be different and there will be a signal at one or other of the 90° positions.

This, then, forms a very sensitive test for asymmetry and, in ships fitted with B-T gear, a "Symmetry Tester" is sometimes made a permanent part of the installation, and the buzzer is switched on momentarily and the search coil rotated before each group of bearings is taken in order to ensure that, owing to rough weather or other causes, some mishap has not occurred to the aerial system. If the four patches of sound are separated by sharp zero points, corresponding to the 90° positions, it is quite safe to assume that everything is in order. This test does not, of course, detect errors in calibration, but once the aerial has been made to the correct size to give accurate bearings, it is unlikely that anything can happen to it which would affect the accuracy of the bearings without, at the same time, introducing a certain amount of asymmetry which would at once be noticed.

CALIBRATION

On completion of the installation and testing up to this stage, the next task is to obtain as full a set of bearings as possible on transmitters, the directions of which are accurately known, the plotting of which will normally display the large quadrantal error typical of the steel ship D.F. Before taking these bearings and making any final adjustments, it is essential that the ship's rigging should be complete and any stays that have been slacked off in port should be replaced. Booms should be stowed, removable sections of rail and large steel boat davits should be in position and the ship should be as nearly as possible in her sea-going trim. The larger the vessel, of course, the less will be the effects of these possible sources of error, particularly when at a great distance from the D.F. loop.

It will not, as a rule, be found possible to attain these conditions until the working of cargo has been finished—at any rate for the day—and it is therefore advisable to complete the D.F. installation as long as possible before the ship sails, in order that Sundays, holidays, meal hours and other periods when cargo is not being worked, may be utilised for this most important part of the work. If everything goes smoothly, the whole operation may not take more than an hour or two, but unforeseen difficulties frequently arise and it is usually most undesirable to allow a ship to sail with uncalibrated gear, particularly if she is likely to be absent for a long period. On the other hand if the telegraphist understands his work, and if the ship authorities appreciate the situation and promise co-operation, then calibration may be, and often has to be, done at sea.

When the ship is lying in dock, her position, and the positions of various available transmitting stations can be located on a gnomonic chart, and the true bearings of the latter measured off with a protractor. It is, of course, also necessary to know the direction of the ship's head and methods of finding this in various circumstances are described in Chapter 17,

In choosing stations, on which to take bearings for calibration, it must be remembered that stations dead ahead, astern or abeam, are practically useless as, provided any asymmetry has been eliminated, and the D.F. aerial is on the centre line of the ship, bearings in these directions will almost invariably be correct. Transmitting stations on the bow or quarter are required and two or three stations will be quite enough provided that the errors appear consistent.

Calibration when Ship is at Anchor or Moored. In cases where the ship lies near large cranes, alongside warehouses or within a few hundred yards of large gantries, errors other than those introduced by the hull of the ship are to be expected and in these circumstances, satisfactory calibration will be impossible. It may be found, for instance, that bearings vary with the movements of a neighbouring travelling crane, and in such a case it is better to wait until the ship moves away from the place and is either anchored or under way on a steady course.

When the ship is at anchor, the D.F. readings of the transmitting stations are tabulated against the corrected compass readings, and the true bearings of the transmitting stations according to the D.F. are found by the following rule :

$$\begin{array}{c}\text{True Bearing}\\ \text{of Station}\\ \text{by D.F.}\end{array} = \left\{ \begin{array}{c}\text{D.F.}\\ \text{Reading.}\end{array} + \begin{array}{c}\text{Corrected}\\ \text{Compass}\\ \text{Reading.}\end{array} \right\} - 360^\circ \quad \begin{array}{c}\text{(If result}\\ \text{greater than}\\ 360^\circ)\end{array}$$

Observations may be tabulated thus :

Station.	D.F. Reading.	Corrected Compass Reading	True Bearing of Station by D.F.	True Bearing of Station from Chart.	Error.
GNF	275°	336°	251°	249½°	+ 1½°

$$(\text{Where } 275^\circ + 336^\circ - 360^\circ = 251^\circ)$$

Ship Under Way. A similar procedure is necessary when the ship is under way, but the problem is complicated by the fact that the ship is moving, so that its position has to be plotted out on the chart for each reading and the bearing of the distant station measured off. The true bearing of the ship's head in these circumstances will always be taken from the compass, after applying the corrections for variation and deviation.

In carrying out calibration after a ship has sailed, care must be taken not to interfere with the ship's wireless service, and in any case it is unlikely that any extensive help will be obtained from the bridge until after the pilot has left, unless circumstances are very favourable. It should be remembered that calibration is practically impossible when the ship is under way, unless she is on a set course and this is rarely the case until some considerable time after she has sailed. Even then, if the ship yaws at all or swings off her course, as she usually does, calibration becomes a laborious, intricate and temper-testing operation by comparison with the far more convenient method mentioned below.

Special Transmitters for Calibration. It has been mentioned that the calibration of a shore station is sometimes effected by taking simultaneous optical and wireless bearings on a mobile transmitting station within a few wave lengths of the D.F. station. Conversely, when a considerable number of ships are being fitted with D.F. installations and calibrated at the same port, it may sometimes be worth while to have a special low power transmitter on shore in an exposed position.

To gain the best results the ship should either be at anchor or moving very slowly, and in any case she should be in such a position that the transmitting station is on the bow or quarter. If time permits of the ship being swung—which is extremely unlikely—an excellent calibration may be made. This procedure is always carried out during the magnetic compass trials but the wireless compass is not as a rule similarly favoured, and there is a somewhat slender hope of being able to carry out the two operations at the same time.

Some of the advantages of the special calibrating station are lost if the ship be in a position from which the station is not visible, as the accuracy of the work depends largely on the fact that optical bearings can be taken by means of a bearing plate or azimuth mirror, at the same instant as the D.F. bearing, and thus the compass error is eliminated.

The lighthouse authorities of the U.S.A. provide, on application, special transmissions from W/T fog signals and beacons for calibrating purposes, subject to precautions to avoid interference with other beacons in the same frequency band. The affording of similar facilities in this country is under discussion.

QUADRANTAL ERROR

It has been stated on page 90 that the electromagnetic field in the neighbourhood of a ship's D.F. aerial can, in general, be resolved into two components. These are :—

(1) A field in phase with that of the wanted signal but not necessarily arriving from the true direction, and

(2) A quadrature field, making with the above an angle which depends on the relative positions of the surrounding metallic masses.

It was also seen that the effect of the second of these waves, namely, blurred cosine minima, could be sufficiently reduced by the introduction of a balancing e.m.f. to enable bearings to be taken on one sharp minimum provided that the quadrature component was not too large.

It is with the first or " main " component of the field that we are now concerned and particularly with the angle that this field makes, at the D.F. aerial, with the main field from the distant transmitter, since this is the error of the D.F.

Pages 349 to 368 of Chapter 9 should be read in conjunction with what is said below as there is much in common between the ship and shore station calibration problems which need not be repeated. As in the latter case, the first thing to be done after a set of check bearings has been taken, is to plot an error curve, the shape of which will reflect the skill or luck in the choice of position for the aerial.

Since the error of the main component of the ship's field is due to re-radiation and the distorting effect of the hull and metal work of the ship, it is found, as would be expected, that the direction of the field is always warped towards the centre line of the ship, as in Fig. 346, provided that the D.F. aerials are themselves erected in an open site on the centre line and that the ship's superstructure is reasonably symmetrical on the port and starboard sides.

Thus, a station, the correct relative bearing of which is 45°, would read, say, 30° and similarly a transmitter at 135° would read 150°. If, under these conditions, a series of bearings be taken and the errors plotted against correct relative bearings, a curve will result that is negative on the

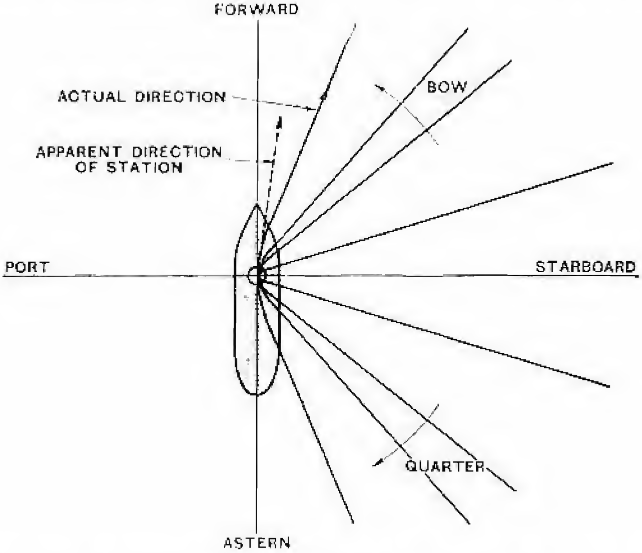


Fig. 346.—Distortion of Apparent Bearings towards Fore and Aft Line of Ship.

starboard bow, that is, from 0° to 90°, and changes sign in each succeeding quadrant, as in the solid curve of Fig. 347 (*a*).

If the errors be plotted against scale reading, or observed bearing, the dotted curve of Fig. 347 (*a*) results, this being displaced from the solid curve at every point by the amount of the error. It will be noticed that neither curve is symmetrical about the vertical dotted line *ab* through the 45° scale reading, although the maximum positive and negative errors are equal, namely +13° and −13°.

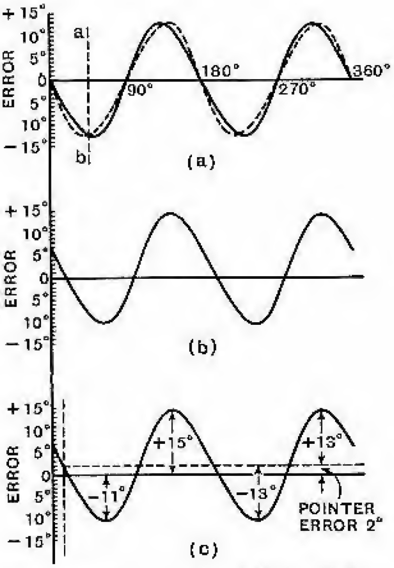


Fig. 347.—Analysis of Ship D.F. Error Curve.

If the aerial has been rigged say 20 to 40 feet away from the centre line of the ship, a less symmetrical Q.E. curve may be expected, for which there are errors in the fore and aft directions and also abeam. If, as is not uncommon, a pointer error also exists, a curve of the form shown in Fig. 347 (*b*) will result.

The pointer error is at once obvious, since the positive maximum errors are 15° whilst the negative maxima are 11° so that drawing a revised base line, as shown dotted in Fig. 347 (*c*), this gives the curve after correction of the pointer error.

There is still, however, an error of +4° ahead and astern and of —4° on either beam, and this is due to the aerials being situated in a position where the main component of the ship's field is not parallel to the ship's centre line and it is sometimes referred to as the **Ship's Field Error.** The forward direction of zero error is shown by the vertical dotted line which intersects the scale line at about 15°.

An unsymmetrical curve, with a symmetrically situated aerial site that is apparently free from obstructions, would point to unbalance in the aerial or feeder system in the case of B-T aerials and this should be first investigated.

Asymmetry that takes the form of a considerably larger or smaller error in some quadrants than in others may nearly always be put down to a metal stay or one of the other forms of obstruction that have already been mentioned.

A reminder may also be included here that errors can be introduced due to the shape of the aerial of the transmitting station and it becomes increasingly advisable to watch this point when the number of stations available for calibration purposes is small. Wireless beacon transmitters, or any station that has an omni-directional aerial with the minimum of horizontally polarized radiation, should be used in preference to the inverted L type of aerial which is known to be unreliable in this respect. The subject has been treated mathematically by J. F. Coales (3307). Further examples of error curves are given in Figs. 348 and 351.

Variable Quadrantal Error. The Q.E. usually changes with the draught, and in the majority of cases the maximum Q.E. unloaded is about one and a half times that when the ship is fully loaded, although the ratio may be as much as 2 : 1 and is at times reversed. This point must be checked by calibration under each condition and separate correction tables or graphs kept for use as the occasion demands. Examples of the effect are shown in some of the correction curves of Fig. 348, the draught in the case of ship (*d*) varying from 20 feet aft and 10 feet forward for curve 1, to 25 feet aft and 24 feet forward for curve 4. The calibration has also been known to be affected when the cargo has consisted of metal.

Q.E. is dependent, furthermore, on wave length and as a rule increases, in a steel ship, as the wave length decreases from, say, 1,000 to 300 m. This is not very important in merchant vessels but becomes a problem in H.M. ships, where a multiplicity of D.F. waves is required.

Although Q.E. has been shown to be a possibility on a shore station, it is in connection with the marine case that the bulk of investigations on the subject have been carried out. Mesny, in particular, in a classic paper (2012) has dealt very completely with the mathematical analysis of the effect of the hull of a ship, as have also several other writers, mentioned on page 90.

Calibration Using Synthetic Q.E. Curves. Occasions may arise in which only one or two satisfactory check bearings can be taken before the ship sails, or conditions become unsuitable for further testing. So long as tests for aerial symmetry, and also visual observations, point to the site being a good one, and if the bearings can be got on the bow or quarter, a reasonably satisfactory calibration may be made by assuming a symmetrical Q.E. curve and drawing this through the two points—or even through one point in an emergency.

The behaviour of the hull of a steel ship, when energized by an electromagnetic wave, approximates to that of a large loop situated below, and magnetically linked with, the fore and aft position of the D.F. loop. On the assumption that the hull behaves purely as a loop, the relation between the correct relative bearing ϕ and the uncorrected D.F. bearing θ, relative to the ships' head, can be represented by :—

$$\text{Tan } \phi = A \tan \theta.$$

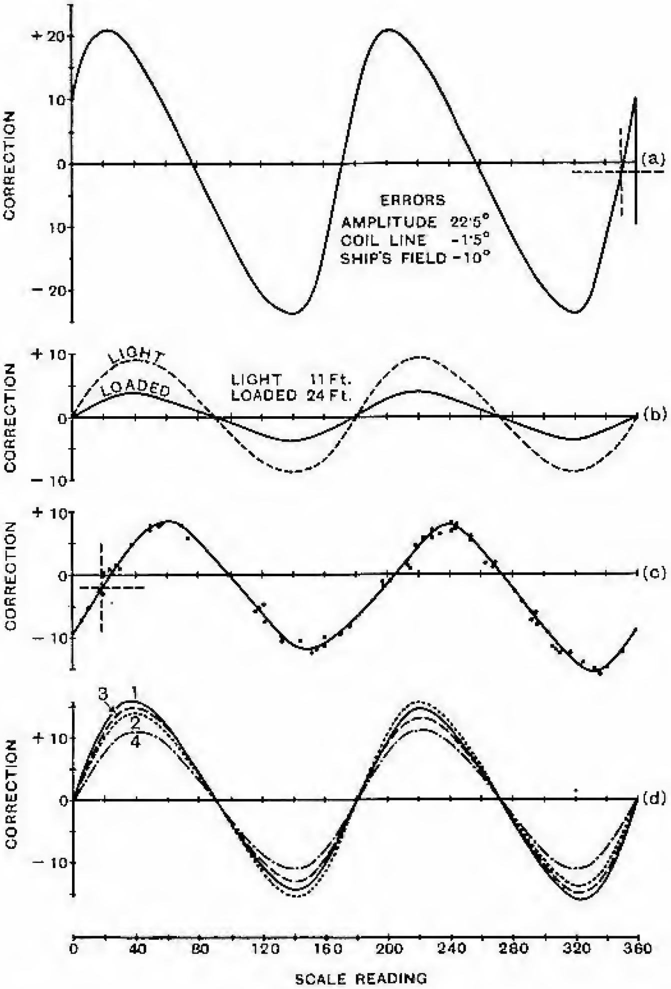


Fig. 348.—Examples of Ship D.F. Correction Curves, showing, in (*b*) and (*d*), Effect of Draught.

where A is a constant depending upon a number of factors concerning the ship, aerial loop disposition, etc.

Based upon this principle, N. Lea (2929) has described a rapid method of obtaining a Q.E. curve from a minimum number of check bearings in the following simple manner.

Making use of the above expression, a family of curves of varying peak values are derived, as shown in Fig. 349 and these, when drawn out on tracing paper, can be adjusted over the proposed Q.E. correction graph of the ship which has been made from the one or two observed values of Q.E. By choosing the curve which most nearly fits the observed errors, this may be taken with a fair degree of safety as a basis for a correction curve.

Checking During Service. When the ship is at sea, the calibration should be checked whenever possible by taking bearings on visible transmitters such as light-ship beacons and other ships—though always bearing in mind, in the latter case, the error due to unsymmetrical aerials at close quarters.

In particular should a check be made after any structural alteration in the transmitting aerial of the ship or her rigging. One additional wire stay may necessitate a completely new correction chart.

CORRECTION OF ERRORS

Reduction of Quadrantal Error with B-T Aerials. When using large B-T loops, the bulk of the correction can be done by reducing the area of the fore and aft loop, as in the case of the shore station, final trimming being done by chokes. Resistance may be added in the case of the aperiodic aerial but the resulting calibration is less stable with change of wave length than is the choke method. When the amount of reduction is estimated during construction of the aerial, this reduction may be overdone, and this is at once made known when a check bearing is taken as the error is found to be positive on the starboard bow and port quarter instead of negative, as is the case when the fore and aft loop is too large.

When the calibration is complete, note should be taken of the sizes of the two loops and a dimensioned sketch made so that, in case of accident, a new aerial can be rigged with a minimum of delay and without the necessity of re-calibration.

Series and Parallel Chokes. After preliminary adjustment of large B-T loops, and as the usual method of correction in the case of the small fixed loops of the types shown in Figs. 335 and 338, series or parallel chokes are used. Series chokes have the disadvantage that, when a big bearing swing is needed, the amount of choke will have the effect of appreciably raising the natural wave length of the loop, and may introduce loop tuning error. Also owing to the change in the electrical constants of the loop, there may be misphasing of the loop currents with consequent indefinite minima.

The parallel choke, of course, reduces the natural wave length of the loop, and also is found to make the resulting calibration less sensitive to changes of wave length. Horton (3104) gives actual inductance and capacity values for certain large B-T aerials with long connecting cables, and points out that by adjusting the capacity of the cables by added condensers in conjunction with parallel chokes, the calibration can be made to hold for wave lengths from 2,000 to 450 m.

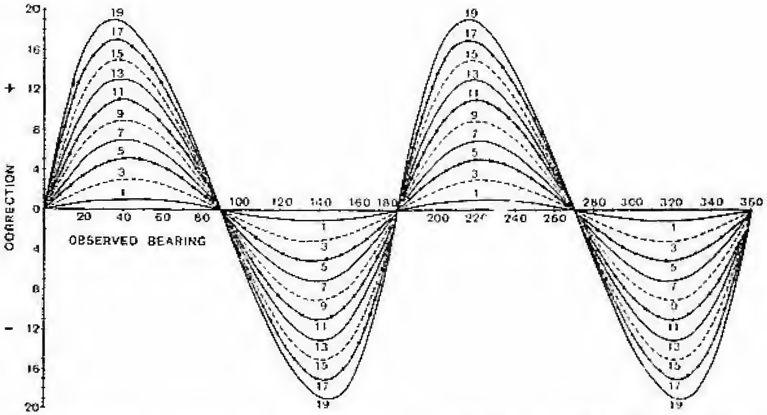


Fig. 349.—Synthetic Q.E. Correction Curves for Rapid Calibration (*Marconi Review*).

Quadrantal Error Correction by Adjacent Closed Loop. If a D.F. loop has a second closed loop erected in its plane and approximately concentrically with it, the magnetic field due to the circulating currents in the closed loop will link with the D.F. loop in such a sense as to reduce the signal e.m.f. It has already been seen, however, that the effect of the hull of a steel ship, considered as an adjacent loop that is below and not concentric with the D.F. loop, is to increase the signal e.m.f. in the vertical plane through the centre line of the ship.

If, therefore, the fixed concentric loop have its plane parallel to the centre line of the ship, it should be possible to balance the hull effect and the concentric loop effect and reduce the residual quadrantal error.

This balance can be obtained, but two sources of residual error exist in the normal practical case. The first of these is that whilst the correction effect of the closed loop is likely to be symmetrical, the actual quadrantal error curve is often unsymmetrical. The second point is that if the closed loop be comparable in size with the D.F. loop, and be placed near enough to have adequate effect, the coupling law between them when the D.F. loop is rotated will, like the simple radiogoniometer, have an octantal component. This residual octantal error can be reduced by the use of large correcting loops as mentioned later.

Small Twin Correcting Loops for Quadrantal Error. An example of the small correcting loop is shown in Fig. 401, which illustrates a pair of D.F. loops mounted below the hull of a German airship. Here it will be noticed that two correcting loops are used, one on each side of the rotating loop, and the dimensions for an average equipment for medium wave working are shown in Fig. 350.

Adjustment of the effect of the correcting loops is obtained by having a 5 mm. break in their circumference across which is connected a variable choke as shown.

The residual octantal error increases with the amount of quadrantal error to be corrected, and its extent for the system shown in Fig. 350 is approximately as follows :—

Max. Q.E.	Residual Octantal Error.
7°	0.5°
11°	1°
16°	2°
19°	3°
22°	4°

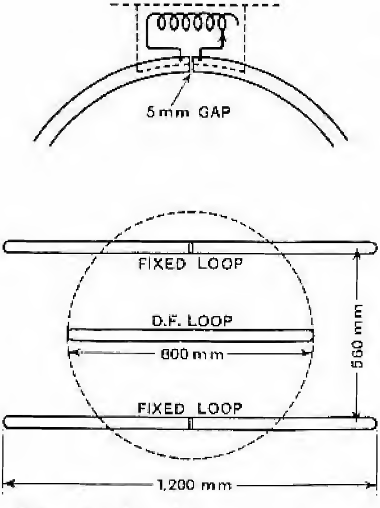


Fig. 350.—Fixed Correcting Loops.

For Q.E. above 15° max. a second residual effect appears, but this reaches a maximum of only 1° for a maximum Q.E. of 25°.

Although illustrated in the above instance as applied to an airship, the method is used in ships and may be seen in use in German war vessels and also in a somewhat modified form, in certain commercial installations in this country.

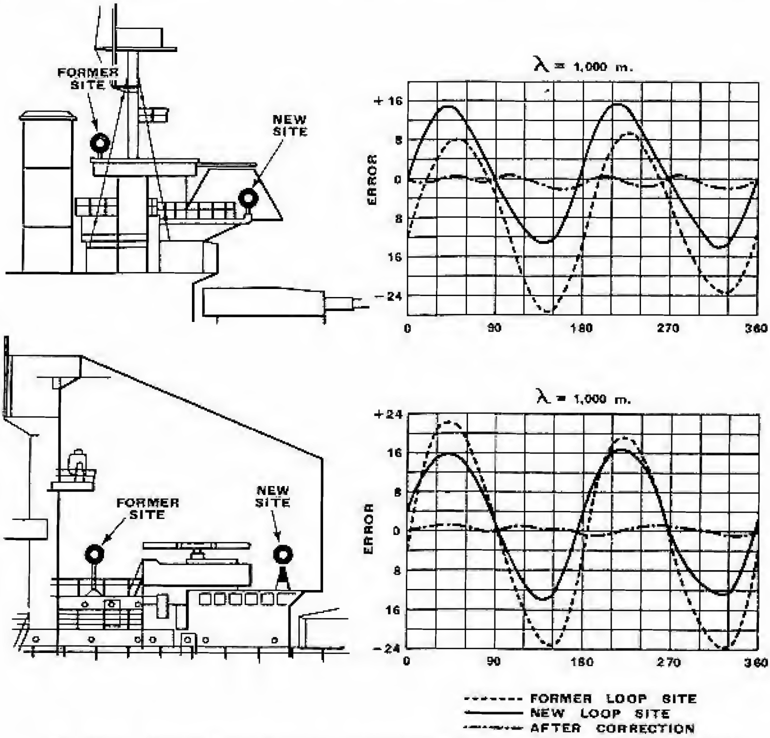


Fig. 351.—Reduction of Q.E. by Combination of Improved Site and Large Fixed Correcting Loop.

Large Correcting Loops for Quadrantal Error. The use of correcting loops employing portions of the ship's rigging is dealt with in detail by M. Wächtler in reference (3218) from which have been extracted the examples shown in Fig. 351 with their associated original and corrected Q.E. curves. It will be noted that in each case the precaution has been taken to move the D.F. loop to a site where the Q.E. is reasonably symmetrical before attempting correction, and the improvement in this respect is very marked. The dotted curves show the original Q.E. when the loops were, in one case between the funnel and the mast, and in the other, immediately forward of the mast. In each case the residual error is of the order of 1° to 2°, the octantal component being noticeable in the upper diagram in Fig. 351, where a smaller correcting loop is used, and absent in the second case. Further examples are given in the reference quoted above.

Special Radiogoniometer for Correcting Quadrantal Error. An ingenious method of maintaining the correct calibration of a B-T ship installation, and at the same time using loops of equal area and electrical constants, is by the use of a form of double radiogoniometer somewhat similar to that used for multi-channel working (Fig. 166). In this case, however, the instrument, whilst having two search coils, connected in series, has only a fore and aft field coil coupled to one search coil, and only a thwartship field coil coupled to the other.

Calibration for the elimination of quadrantal error is effected by reducing the number of turns on the search coil of the fore and aft radiogoniometer.

This instrument is described by C. E. Horton (2318) who mentions the following additional special features in connection with it. Equal aerials can be used; the dampings of the aerial circuits are equal, allowing damped waves to be received without risk of indefinite minima; the use of tuned loops is simplified, since the tunings and resistances of the loops are identical; and lastly, the correction for quadrantal error is true for all wave lengths for both tuned and aperiodic loops.

Mechanical Compensators. The possibility of mechanical correction of Q.E. was briefly mentioned in Chapter 9, but it is far more commonly applied in the ship than in the shore D.F.

Whilst each is more convenient than the correction chart, the mechanical compensator and the methods so far mentioned for reducing the effective signal in the fore and aft line of the ship are different in principle, and each has its disadvantages. The mechanical device can generally be arranged to correct any error that is found during calibration, but the other methods are unable to take account of errors that do not lie on a smooth and symmetrical quadrantal curve. On the other hand, the mechanical corrector usually introduces an error if owing, say, to weak signals, swing bearings have to be taken with the rotating frame to which it is fitted (see page 445) whilst the systems involving reduction of fore and aft signal are free from this disability.

Cam Compensators. The best known of these mechanical devices is probably the cam compensator, the principle of which is that the D.F. pointer is not rigidly fixed to the spindle of the rotating frame, but, by means of a cam and link mechanism, is advanced or retarded on the orientation of the aerial to allow for quadrantal and other errors. It can equally well be applied to a radiogoniometer for the correction of the main Q.E. or the residual errors if any.

An example of this type is shown diagrammatically in Fig. 352. It was patented by the Telefunken Company in 1928 and the principle is used in their ship D.F. described on page 448.

The arm B rotates with the loop spindle S and has, pivoted at X, a lever L, the other end of which controls the pointer P. The roller attached to L is held against the periphery of the cam C by a helical spring. If the cam were circular, the pointer P would rotate uniformly with the spindle S, but when the roller is on a low section of a correcting cam the pointer reads less than the loop bearings, whilst, when the cam is high, the pointer rotates clockwise to some position R and gives a positive correction.

In practice, the apparatus is constructed so that the cam is readily accessible, the pointer may have a compass card associated with it so that corrected True Bearings may be read direct, and provision is sometimes made for marking cam blanks during calibration so that the cam can be cut and fitted immediately.

A compensator similar to the above in many respects is described in (3104), having been developed in H.M. Signal School, Portsmouth. This paper deals also with the design of cams and mentions the possibility of a solid cam of varying pitch, arranged so that the roller can move along it from a circular portion of " no correction " to the other end, where maximum correction is obtained. An application of this would be in the case of ships whose Q.E. varies largely with their draught. The discussion of this compensator is continued in (3406).

Designs of compensators have appeared in which the hand-wheel spindle and pointer have the same motion, but cam-driven gearing is interposed before the spindle reaches the rotating frame. The results are the same as before, but the gearing now has to be robust enough to control the frame and not merely the pointer.

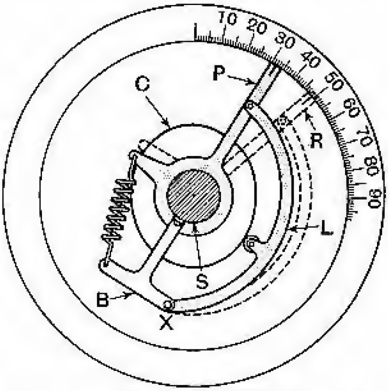


Fig. 352.—Principle of Telefunken Cam Corrector.

If a mechanical compensator is not dependent on a cam for its law, but depends instead upon some form of gear mechanism, it will in general be unable to take account of departures from the smooth error curves of the form shown in Fig. 349.

Since the law involved in these curves is :—tan ϕ=A tan θ (page 434), it is clearly necessary that any correcting device shall have a reciprocal law and such actually results from certain types of epicyclic gearing and also from the Hooke's Universal Joint as used in motor car transmission.

The " Sun and Planet " mechanism can also be adapted to the same purpose and has been used to a considerable extent. (British Patent 315990, F. P. Best and Radio Communication Company Ltd. 1929)

TAKING BEARINGS

The actual taking of bearings with a ship installation does not differ greatly from the method already described for the shore D.F., with the exception of the precautions necessary regarding swing bearings, given below. There are, however, some special features in certain makes of ship D.F. and a few of these are described on pages 447 to 461. The chief disparity is in the conditions under which the work has to be done and practice is necessary, as well as experience of the behaviour of the ship in different types of seas, in order to get consistent bearings.

The notes given below assume that the D.F. is installed in the wireless office. As already stated, the operations are simplified if the navigator takes his own bearings in the wheel house and the modifications necessary in procedure will be obvious to the reader.

D.F. Routine. On the receipt of instructions to take bearings on one or more stations, the telegraphist acknowledges the order and takes steps to get into communication with the stations, unless they already happen to be engaged on traffic, or are beacon transmitters, making it unnecessary to ask for a special transmission. If bearings are asked for on a station which has a " bad bearing " sector in the direction of the estimated position of the ship, or if there appears to be a likelihood of coast refraction or night effect, if the ship be sheltered from the transmitting station by high cliffs or if the latter be situated so as to be likely to cause reflection, with distortion of the direction of the wave front, these facts should be brought to the notice of the navigating officer. As soon as the required station is heard, a stand-by signal, say two strokes on the gong, is sent to the bridge as a warning to hold the ship as steady on her course as possible and to be ready to note the compass reading on receipt of further gong signals.

As a reading is taken on the D.F., a signal, say, one stroke, is sent on the gong and the telegraphist and the helmsman both log their readings and the time. As long as the station continues to transmit, further bearings are taken, gong signals being sent each time until about five have been obtained. If the bearings are taken at very short intervals there is no necessity to log the time of each, but successive readings should be numbered 1, 2, 3, etc., by both telegraphist and helmsman.

When special forms are supplied for logging the bearings space may also be left for the latitude and longitude of the station to be filled in by the telegraphist. There is an advantage in doing this in that sometimes there are two wireless stations near the same port, or the name of the wireless station may be different from that of the port it serves, or, on the other hand, the station may take the name of the port, and yet be situated some miles away. In any of these cases, confusion might arise. The telegraphist has full information on all these matters and may often be in a better position to know the details of the station on which bearings are being taken.

Sometimes it may happen that when one bearing has been taken on station A, this station stops transmitting and station B is heard. In such a case it is advisable to take bearings of B and to return to A later when he is heard again. So long as the gong signal is sent for each reading, and the successive readings are numbered and also timed where possible, there is no chance of confusion when the log sheets are handed in to the bridge. An effort should be made on the part of the wireless staff and navigating officers of the ship to arrange a routine in connection with the D.F. work, when all possible sonrces of confusion can be given special attention and the whole operation brought to a state of efficiency.

Any bearing which seems a doubtful one should be marked to this effect so that if it differs widely from the remaining ones on that station it may be neglected, rather than averaging it in with the others. Some further remarks on the averaging of bearings appear on page 554.

As soon as the work is completed, a finishing signal, say three strokes on the gong, should be sent to the bridge and the log sheets filled in and sent up.

True Bearings. In the case of a rotating frame installation on board ship, the frame is sometimes located vertically over a magnetic compass and the two instruments are so combined that the D.F. pointer operates on the compass card, enabling true bearings to be obtained after the application of the compass correction. The ideal combination, as already stated, is doubtless that in which the scale of the direction finder is controlled by a gyro-compass, or failing that, in which a repeater dial is fitted alongside the D.F.

A True Bearing Indicator may be used in conjunction with the gyro-compass repeater, this consisting of a link motion which allows the control of a radiogoniometer to be coupled to a rotating projector which throws a beam of light on to the card of the repeater dial, corresponding to the position of the pointer of the radiogoniometer. It must be remembered, however, that the repeater is not infallible and an opportunity should be taken to check the wireless office repeater against the one on the bridge in order to ascertain whether the instrument itself is working properly.

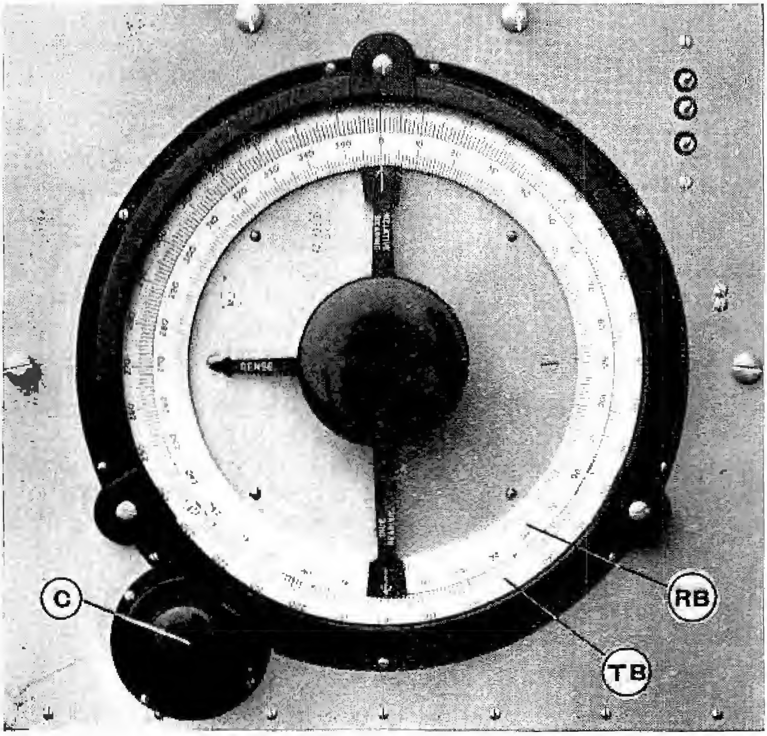


Fig. 353.—Radiogoniometer with Fixed Relative Bearing Scale (RB) and Movable True Bearing Scale (TB) Controlled by C (Marconi).

Yet another method is to have a **Dumb Compass Card,** that is to say, a scale that can be rotated to a position such that North on the scale is pointing to True North when the ship is on her proper course. If, under these conditions, the helmsman gives a signal when the ship is steady, the telegraphist can get a snap bearing which is a True Bearing and needs no further correction. See Fig. 353.

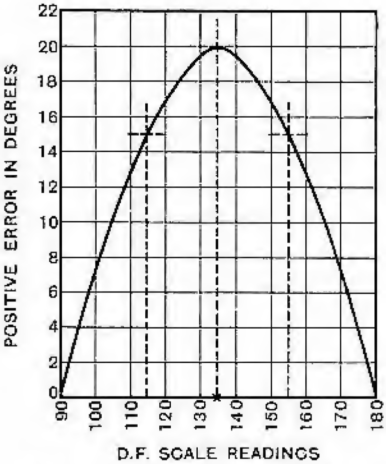


Fig. 354.—Illustrating "Swing Bearing Error" when using Mechanical Compensator.

Swing Bearings and Mechanical Q.E. Correctors. The result of an asymmetrical polar curve due to zero-cleaning has already been mentioned in its relation to swing bearings, and still greater errors are liable to occur if swings are taken with most forms of Q.E. compensator or corrector.

Suppose that a maximum Q.E. of 20° exists and that this is being corrected by means of a cam compensator. A quadrant of the error curve is shown in Fig. 354 and it is assumed that a bearing has been taken, the spot reading of which is 135° on the scale, where the error is +20°. This means that the direction of the frame is 155° corresponding to a correct relative bearing of 135°.

Now note what the mean frame position would have been if the bearing had been the result of ±20° swings between 115° and 155°. At 115° the error is about +15° and the frame would be at 130°, whilst at a scale reading of 155°, the error would be again 15° and the frame at 170°. But the mean frame position would then be 150°, which is seen to be 5° different from its position for the spot bearing.

The amount of this error decreases with the width of swing and also, of course, with the Q.E. and a series of curves has been prepared by F. P. Best (Marconi Company), two of which are reproduced in Fig. 355 (*a*) and (*b*). The first of these includes the case just discussed, namely with ±20° swings with 20° Q.E., and also down to 5° Q.E. In Fig. 355 (*b*), the swings are ±10°. Another curve, not reproduced, shows that for ±5° swing and a maximum Q.E. of 20°, the error is only

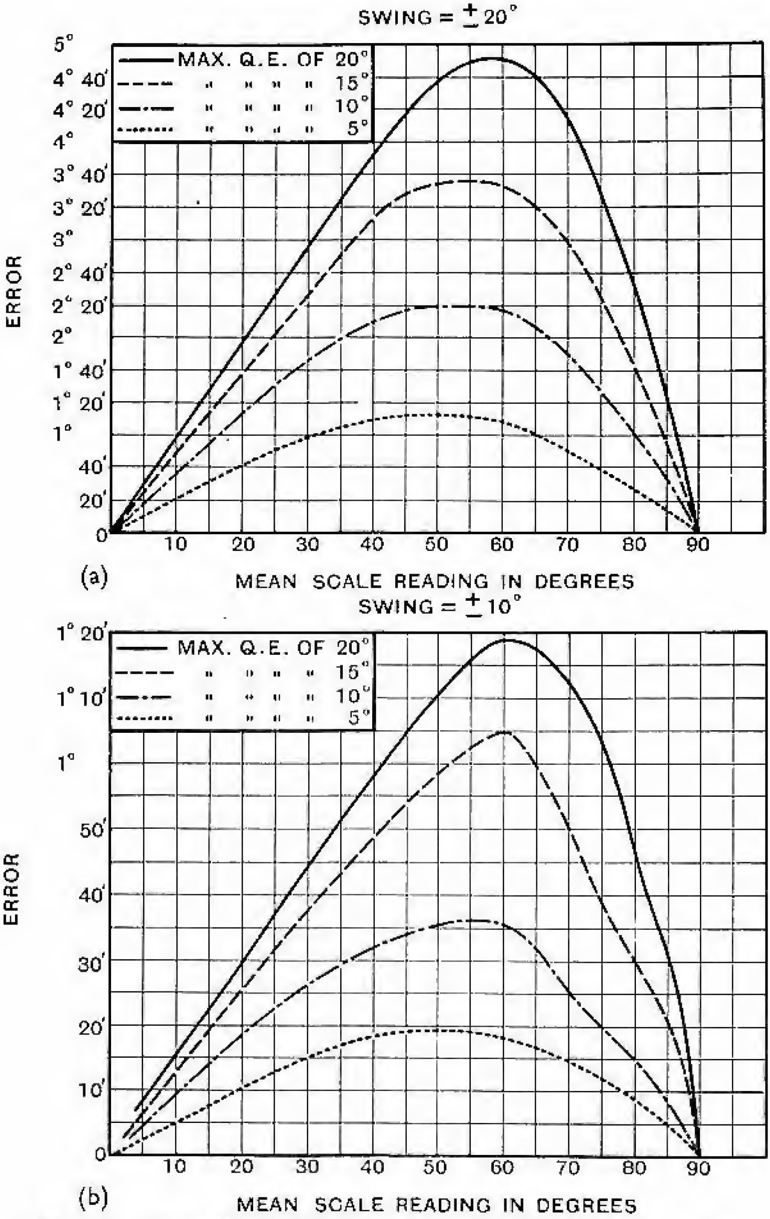


Fig. 355.—Swing Bearing Error for 10° and 20° Swings when using Mechanical Compensator.

about one-third of a degree. These curves have been prepared on the assumption of a symmetrical Q.E. curve, as in Fig. 354.

Note that the above remarks also apply to the D.F. with a specially engraved scale that takes the Q.E. into account.

D.F. in the Wheel House. In this case, much of what has been said above still applies but the details of the routine will vary from one ship to another. In cases where the D.F. is operated by the navigator rather than by the telegraphist, then as already mentioned, it is vitally important that all the deck officers who may be called upon to use the apparatus shall make themselves as expert in its use as they are in their other duties.

The routine should allow of the telegraphist listening on spare telephones for the purpose of identifying ship and shore stations when difficulties arise, and he will presumably be responsible for the maintenance of the gear. Team work and co-operation will come naturally in some ships in arranging these matters and will be more difficult to achieve in others—depending as they do so much on temperaments of individuals.

ROLLING ERROR

When a ship is rolling badly, the axis of rotation of a frame will be appreciably out of the vertical at the limit of each roll. Experiments with a book and pencil (see page 194) will indicate that in certain relations of the fore and aft line of the ship to the direction of the transmitting station, the flux linkage with the loop will vary with the extent of the roll, and can lead to errors in bearings. Various means exist for making allowance for discrepancies introduced in this way, but rolling error is not an important component in the residual error and an intelligent operator will soon learn how to take bearings under such conditions.

EXAMPLES OF MARINE D.F. INSTALLATIONS

This chapter concludes with descriptions of some standard types of ship D.F. installations. Space does not permit full details being given in every case regarding the apparatus, circuit, controls and method of operating, and the more conventional features have been curtailed in some instances.

The primary object of the section is to show the ingenuity displayed in design, and the performance to be expected in commercial apparatus, and not necessarily to give working instructions.

It is also important to bear in mind that the information only represents current practice at the time it was supplied for the purposes of this book and it is liable to become obsolete.

THE TELEFUNKEN TYPE E 374 N SHIP D.F.

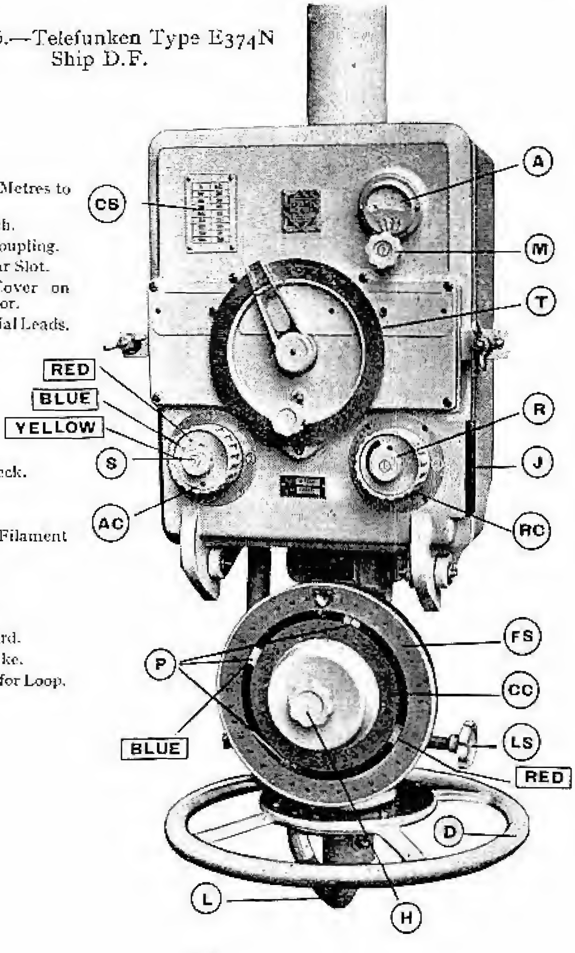
Reference has been made on page 126 to this equipment and a description given of the methods adopted for obtaining a cosine diagram free from antenna and quadrature effects.

The loop used with the more usual direct drive was shown in Fig. 337 and it can also be arranged for remote control.

Scale and Pointer System. Fig. 356 shows the scale and pointer system, in which the outer scale is the fixed one and inside this rotates the composite pointer made up of four parts, namely the line with the black dot for observation of

Fig. 356.—Telefunken Type E374N Ship D.F.

CS.	Conversion Scale, Metres to kc.
S.	D.F.–Sense Switch.
AC.	Auxiliary Aerial Coupling.
P.	Pointers in Annular Slot.
H.	Screw Holding Cover on Cam Compensator.
L.	Tube Carrying Aerial Leads.
A.	Anode Current Check.
M.	Meter Switch.
T.	Tuning Scale.
R.	2nd R.F. Valve Filament Control.
J.	Telephone Jacks.
RC.	Reaction Control.
FS.	Fixed Scale.
CC.	Dumb Compass Card.
LS.	Frame Spindle Brake.
D.	Hand-wheel Drive for Loop.



bearings, the red and blue marks 90° on either side which are used in sense determination, and an unused blank opposite the black dot. Immediately inside this annular space, where the moving pointers rotate, is a dumb compass card.

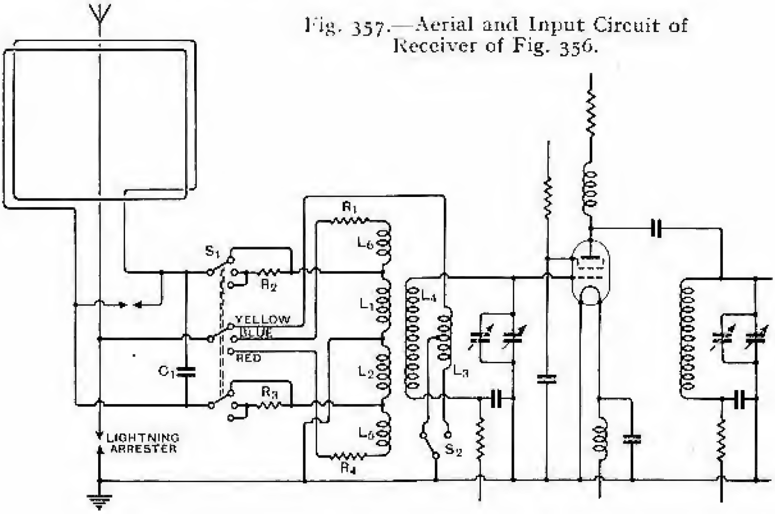


Fig. 357.—Aerial and Input Circuit of Receiver of Fig. 356.

Sense and Bearing Determination. Fig. 357 gives a more complete diagram of the input circuit to the receiver. Sense is determined by putting the switch S_1 over to the blue or red position—as shown in the circuit—in either of which positions an additional loading coil L_6 or L_5, together with a phasing resistance R_1 or R_4, are included in the auxiliary aerial, whilst smaller resistances are also included in the loop circuit thus together providing the requisite phase and amplitude condition for an approximate cardioid diagram.

The switch S_1 is shown as S in Fig. 356, where it will be seen that the three positions are indicated as being coloured yellow, red and blue, yellow being the D.F. position.

The manufacturers favour the finding of sense before the precise bearing, and, assuming that the tuning operations have been carried out, the sense is found in the following way :—

(1) With the switch S_1 in the yellow position, the frame is rotated to either of the positions of minimum signal and the approximate bearing indicated by the black dot is noted.

(2) The frame is turned through 90° to a cosine maximum, so that either the blue or red mark is opposite the bearing just

observed and the switch S_1 is turned alternately to the blue and red positions, noting carefully the changes in signal strength that take place. If the switch gives a minimum signal on red, then the red mark indicates the sense and vice versa.

(3) Next, the exact bearing is found by turning the switch S_1 to yellow, rotating the black dot pointer to the position where correct sense has been found to be, and then adjusting the frame direction and the auxiliary aerial coupling until the sharpest minimum is obtained.

Receiver. The receiver, with hand-wheel drive, etc., is seen in Fig. 356, which also shows the solid construction of the container. There is a flexible coupling between the hand wheel and loop to allow for non-linearity of the spindles, and the frame is allowed a total movement through 400°, thus avoiding the necessity for slip rings.

This model can be equipped with a cable lead-in up to 20 feet in length, for installation where the receiver cannot possibly be fitted directly under the loop. The length of the cable is limited by the factor already dealt with on page 126, namely that the total capacity of the loop, connecting leads and cables must not exceed 0·00018 μfd. With the direct drive, the connecting leads are about 6 feet long, with a capacity of about 0·000045 μfd, and the remaining 0·000135 μfd is made up by means of the condenser C_1. Twenty feet of cable will have a capacity of 0·000135 μfd which thus fixes the distance between loop and receiver, unless special circuit alterations are made.

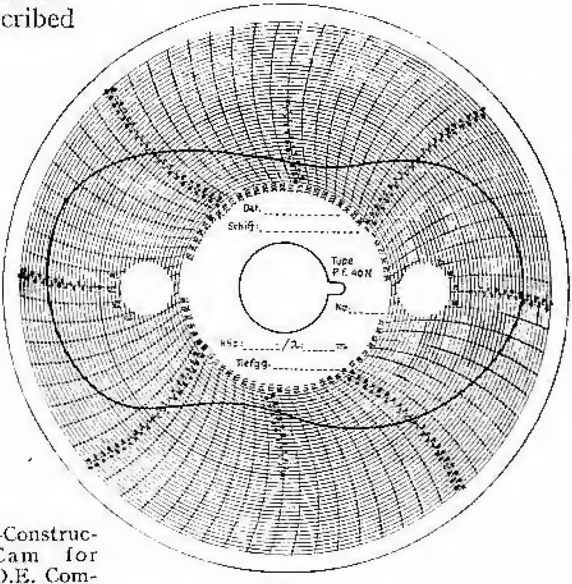
The anode current check is marked for tolerance only and not in actual milliamperes, whilst a spring control on the switch below ensures that it shall always return to the left hand position which checks the feed of the No. 2 R.F. valve—this being the one with the filament control. Space has been saved by concentric controls in some cases.

Receiver Performance. The selectivity of the receiver is given by the following figures for mid range :—

Amount of Detune.	Reduction in Output Voltage.
0·6%	20 db. (to one-tenth)
1·5%	40 db. (to one-hundredth)
3·2%	60 db. (to one-thousandth)

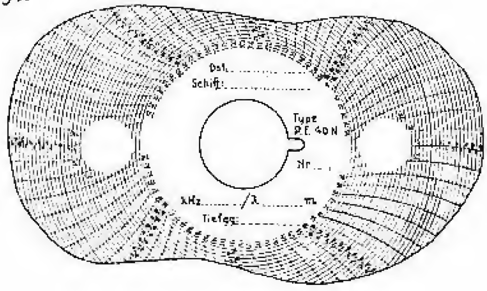
The sensitivity, when receiving with the frame turned to the maximum position, is sufficient to produce an output of one volt across 4,000 Ohms with a field strength of 3 micro-volts per metre, in the case of C.W. Telegraphy, and 10 micro-volts per metre with a Modulated Telegraph transmitter.

Automatic Quadrantal Error Corrector. The mechanism of the pointer drive is arranged so that the pointer automatically indicates the correct relative bearing. Fig. 358 (*a*) shows a form of polar graph which is mounted on thin sheet metal. On the graph paper are plotted values of Q.E., as found when the calibration is done, and a smooth curve is then drawn through the points and the sheet cut out with shears as in Fig. 358 (*b*). This cam, being mounted in the pointer drive mechanism, controls the movement of the pointers as the hand wheel is rotated and applies the necessary correction in the manner already described on page 441.



(a)

Fig. 358.—Construction of Cam for Mechanical Q.E. Compensator of D.F. of Fig. 356.



(b)

RADIOMARINE CORPORATION OF AMERICA SHIP D.F. TYPE ER 1445 C

The input circuit of this D.F. has been described on page 109. A feature of the circuit is the ganging of both the sense and part of the zero cleaning circuit with the tuning control, which ensures good sense determination over the wave range and also the best possible results from the manual adjustment of the coupling L_4 (Fig. 105) when used for zero cleaning.

The remainder of the receiver circuit is straightforward and includes R.F. amplifier, 1st detector, oscillator for frequency changing, 1st and 2nd I.F. amplifier stages, 2nd detector, oscillator for C.W. reception and audio amplifier. The I.F. is 90 kc.

Selectivity. An interfering signal 2½ kc. from resonance is attenuated 20 db. (to one-tenth voltage) and a signal 4 kc. from resonance 40 db. (to one-hundredth voltage).

The Receiver. Fig. 359 shows the upper part of the framework of the apparatus, the base of which is bolted to the deck, the scale and pointer being at a height of about 3 feet to 3 feet 6 inches.

A dumb compass card is used as a scale in the standard apparatus or alternatively a gyro-compass repeater is fitted. Readings of the instrument are taken by observing the card through a piece of plate glass, the upper and lower surfaces having parallax lines engraved on them. A magnifying glass M is fitted for use if required.

The hand wheel H is fixed in a vertical plane and geared to the main vertical shaft through a two to one gear ratio. The advantages claimed for this are that it simplifies the handling of the frame in a gale of wind and there is less difficulty in keeping the loop steady when taking bearings with the ship rolling and pitching badly.

Operation. In taking the bearing, after adjusting for a clear minimum, the end of the parallax lines must be used at which the magnifying glass is fitted, this end being used when calibrating.

A sense pointer, coloured red, is fitted at right angles to the parallax lines. In order to determine sense, the Balance Unit Switch is turned to Sense and the red pointer turned to the observed bearing and its reciprocal, noting the change in signal strength. With the loop in the position of cardioid maximum, the red pointer indicates the correct sense.

If the bearing proves to be in the wrong sense, another must be taken correctly, so that it is obviously an advantage to take the sense first and precise bearing afterwards.

FEDERAL TELEGRAPH COMPANY. NEWARK. NEW JERSEY

Two of the ship designs of the Kolster Direction Finder produced by the above Company are briefly described below and are of considerable interest from the point of view of constructional detail.

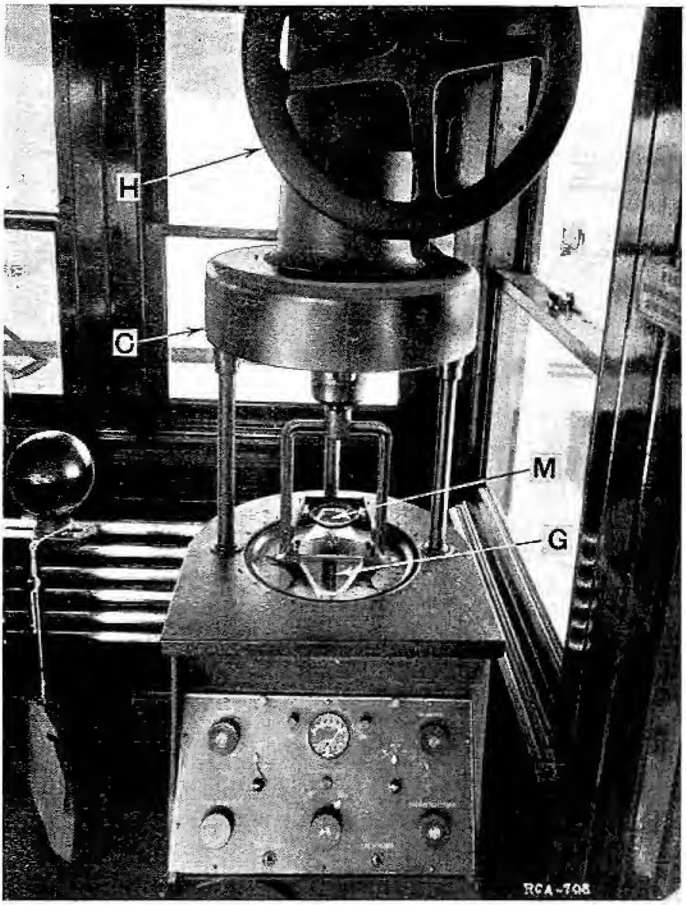


Fig. 359.—Radiomarine Corporation of America Ship D.F. Similar to Type ER1445C. (H) Hand Wheel. (C) Automatic Compensator. (G) Plate Glass with Parallax Lines. (M) Magnifying Glass.

Circuit. Both models have approximately the same input circuit from loop to receiver and amplifier and this is shown in simplified form in Fig. 360.

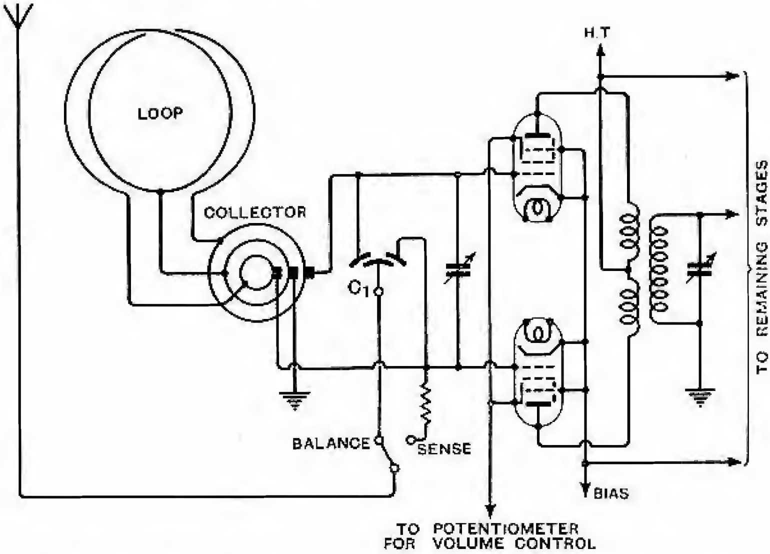


Fig. 360.—Federal Telegraph Co. (N.J.) Ship D.F.'s Types 105 and 102. Loop and Input Circuit.

The earthed mid-point of the loop, together with push-pull input valves and a differential condenser for balancing (C_1) ensures the maximum of symmetry, whilst the balancing condenser also provides correction for quadrature effect. The open aerial used for balancing can be switched over to one side of the input circuit, through a suitable resistance, for the production of a unilateral receiving diagram for sense determination.

TYPE 105 MODEL

This is shown in Fig. 361 and is a binnacle type designed for installation in the chart room or wheel house. The loop is similar to that shown in Fig. 339.

The hand-wheel drive surrounds the scales, which are mounted at about 45° below eye level when standing before the instrument. The outer scale is movable and arranged to be driven by a Sperry Repeater Motor in ships equipped with the Sperry Master Gyro Compass, enabling true bearings to be read direct. There is also an inner fixed scale from which the usual relative bearings are read. On this latter scale is engraved an outline of the hull of a ship to enable the bearings to be visualised.

Fig. 362 shows the mechanism behind the scales, including the collector rings and brushes at the base of the loop column.

The Receiver. The receiver covers a range of 540 to 230 kc. (550 to 1,300 m.), and has five ganged tuned circuits, two of which comprise a band-pass filter at radio frequency. The tuning scale has the usual graduations and is also marked for the positions of the radio Beacons, Ships' Transmitters and the U.S. Navy D.F. Stations.

The selectivity is such that for a constant output of 6 milliwatts into a 20,000 ohm load, the input volts have to be varied as shown below for departures from resonance at mid-range.

Departure from Resonance.	Voltage Input Increase.
0·8%	20 db. (10 times)
1·6%	40 db. (100 times)
2·7%	60 db. (1,000 times)

A loud speaker is mounted inside the top of the binnacle, which has a hinged cover to serve as a reflector, whilst a further receptacle is provided for telephones when not in use.

Q.E. Compensator. This is described in connection with the smaller model below.

Taking Bearings. The cosine diagram minimum is

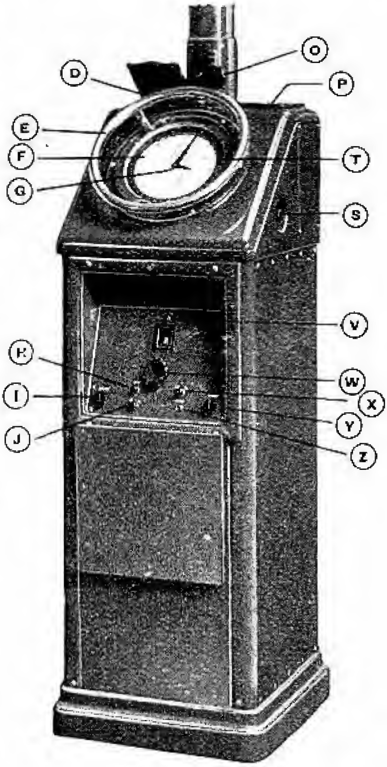


Fig. 361.—Type 105 D.F. of Federal Telegraph Co.

D. Loud Speaker.
E. Hand-wheel Drive.
F. Inner Stationary Scale.
G. D.F. and Sense Pointers.
H. Sense Switch.
I. D.F. Balancing Condenser.
J. On-Off Switch.
O. Brake on Loop Spindle.
P. Case for Telephones.
S. Setting Control for Dumb Compass Card.
T. Dumb Compass Card.
V. Signal Light.
W. Tuning Control.
X. C.W.-I.C.W. Switch.
Y. Volume Control.
Z. Telephone Jack.

sharpened by means of the balancing condenser and spot or small swing bearings are taken, using the long pointer. On pressing the " sense " switch, a unilateral diagram of reception is produced and the two cosine minima positions are inspected by means of the short sense pointer. A D.F. of this type is installed in R.M.S. *Queen Mary* (3704).

TYPE 102 MODEL

This is a rather smaller equipment and is mounted from the upper deck, at eye level. Again it is designed primarily for use in the wheel house, and the receiver controls are much the same as in the Type 105 model, and can be followed by comparison of Fig. 363 and 363 (*a*). No provision is made for the Sperry Compass drive in this instance.

Quadrantal Error Cam Compensator. Fig. 364 shows the scale, pointer and cam compensator dismantled. The operation of the compensator is much the same as of that already described on page 441.

The arm A rotates on a spindle which passes back through the face of the casting to a bevel drive from the hand-wheel and frame spindle. On this spindle, the sleeve S is free to turn, but is controlled by the link L and the bell-crank lever B, with its fulcrum at F. The cam C has been removed, but when in position it slides over S, forming a bearing for the latter, and is fixed rigidly with the roller R riding on its periphery. The portion of S projecting to the front of the cover plate carries the pointer P.

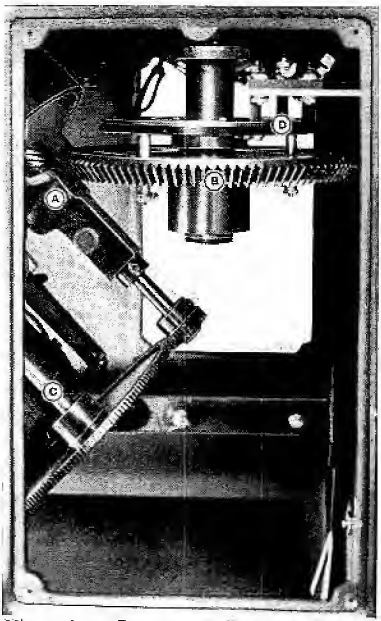


Fig. 362.—Loop and Pointer Drive Mechanism of Type 105 D.F., Fig. 361.

A. Drive from Hand-wheel.
B. Drive to Spindle of Loop.
C. Pointer Drive.
D. Loop Slip Ring Collectors.

If C were a circular cam, then on rotating the hand-wheel drive, A would rotate, R would roll round the cam, keeping always the same distance from the centre, and the pointer would have uniform motion with the drive. With a correcting cam, when R comes to a high position of the cam, the lever B moves outwards about its pivot, the link L is pressed inwards towards the centre and rotates the sleeve S in a clockwise direction relative

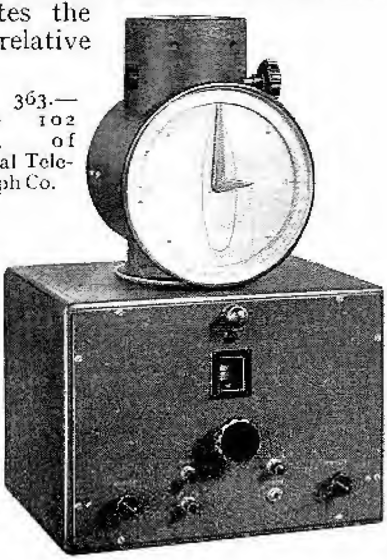


Fig. 363.—Type 102 D.F. of Federal Telegraph Co.

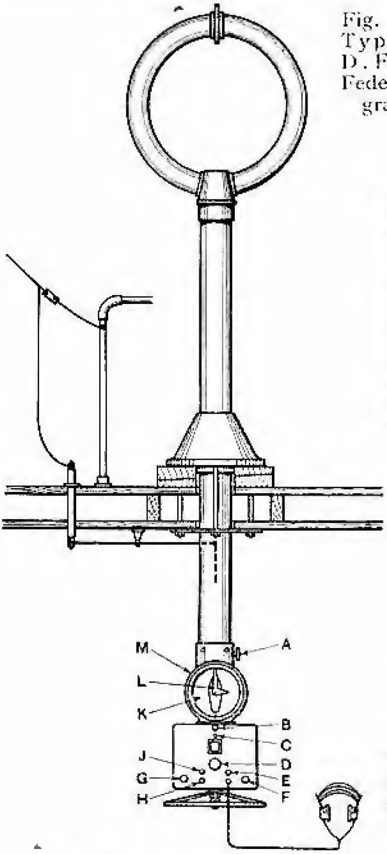
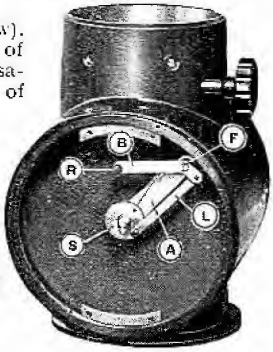
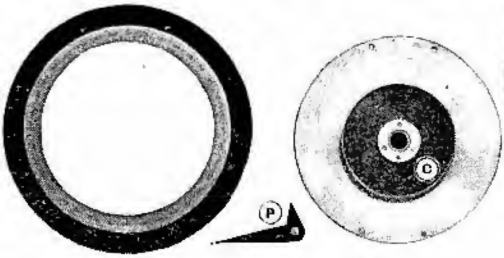


Fig. 363(*a*) (Left).—Key Plan for Fig. 363.

A.	Loop Spindle Brake.
B.	Scale and Panel Light Switch.
C.	Signal Light.
D.	Tuning.
E.	I.C.W.-C.W. Switch.
F.	Volume Control.
G.	Balancing Condenser.
H.	On-Off Switch.
J.	Sense Switch.
K.	Inner Stationary Scale.
L.	D.F. and Sense Pointers.
M.	Dumb Compass Card.

Fig. 364 (Below). Components of Cam Compensator of D.F. of Fig. 363.





to the arm A, so that a positive correction in bearing is produced. A low portion of the cam will give a negative bearing correction, the roller being kept down on the cam periphery by the spring which can be seen coiled round the pivot of B.

MARCONI B-T TYPE D.F.G.11. SHIP D.F.

This apparatus although primarily intended for ship installation is suitable for shore work, in which case it is used with a 70-foot mast and triangular B-T loops. In a ship, either the screened loops of Fig. 338 or the unscreened ones of Fig. 335 are used and can be situated up to a normal maximum distance of 50 feet from the receiver and radiogoniometer, which are shown in Fig. 365. The wave range is 550 to 1,150 m. (545 to 261 kc.) without range switching.

The Radiogoniometer. The radiogoniometer can be fitted in any convenient position to the left of the receiver, to which it is connected by a screened flexible fitting. Opposite

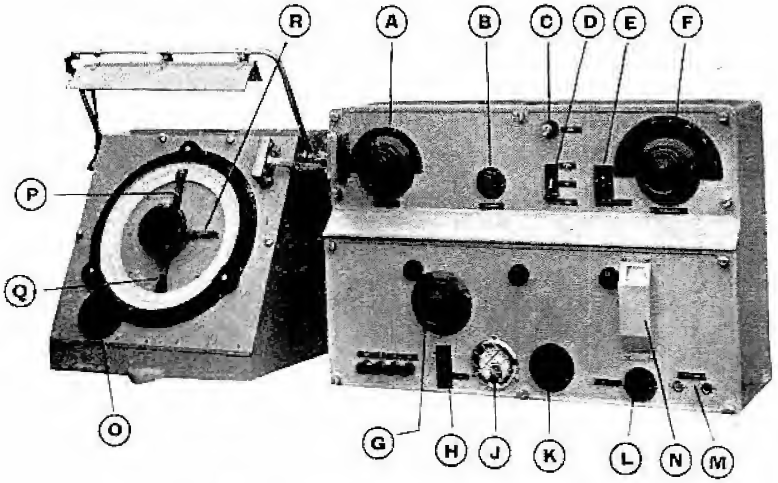


Fig. 365.—Marconi D.F.G. 11 Ship D.F.

A. Search Coil Tuning.
B. D.F. Balance.
C. Open Aerial Connection.
D. D.F.-Sense-Stand-by Switch.
E. C.W.-I.C.W. Switch.
F. Calibrated Oscillator.
G. R.F. Ganged Tuning.
H. On-Off Switch.
J. Volt and Milliammeter.
K. Meter Selector Switch.
L. Volume Control.
M. Twin Telephone Jacks.
N. Tuning Scale.
O. True Bearing Scale Control.
P. True Bearing Pointer.
Q. Relative Bearing Pointer.
R. Sense Pointer.

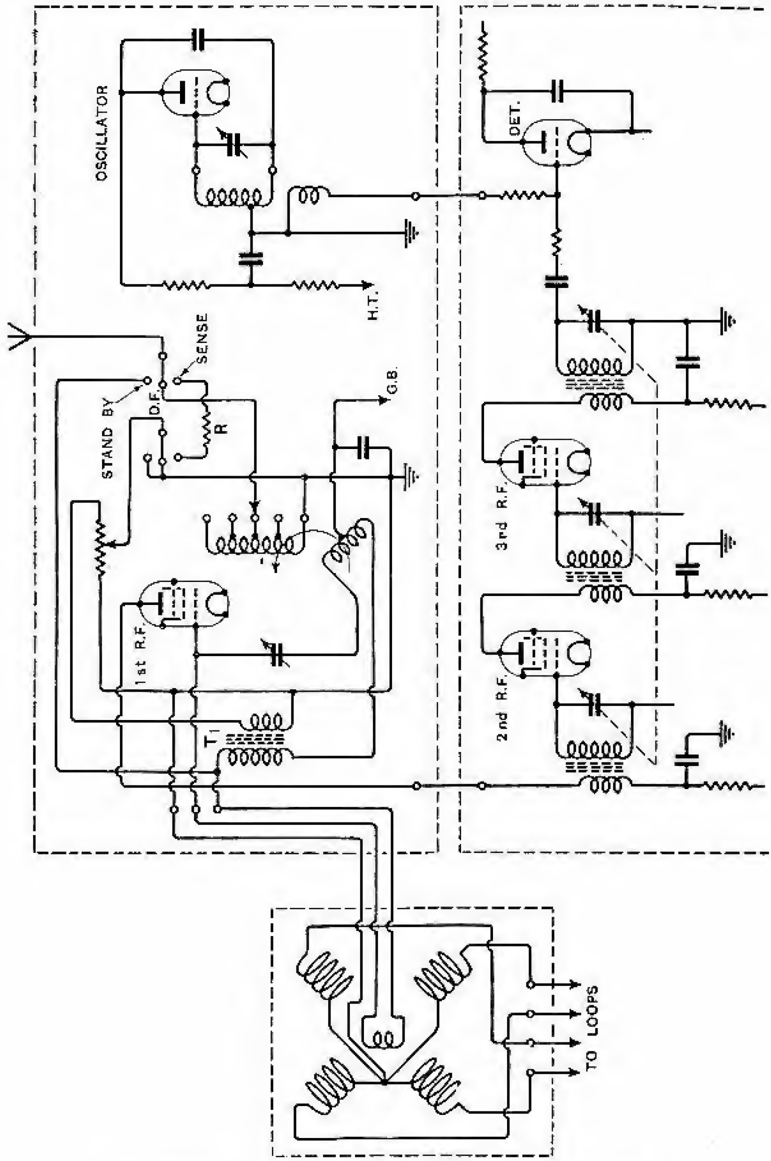


Fig. 366.—Simplified Circuit of Marconi D.F.G. 11 Ship D.F.

ends of the pointer used for taking bearings on the cosine minima are associated with different scales, one of which is fixed for taking relative bearings, and the other adjustable to the ship's head for taking true bearings. The small pointer at right angles is for sense determination. See also Fig. 353.

Circuit. A simplified diagram of connections is given in Fig. 366, whilst Fig. 367 (*a*), (*b*) and (*c*) show the three arrangements for Stand-By, D.F. and Sense.

For D.F., the open aerial is taken to earth through a small loading coil L, and is coupled by the variable mutual M to the search coil circuit. The centre point of the coupling coil in the latter circuit is earthed for radio frequencies.

The open aerial being below tune, a quadrature e.m.f. is induced in the search coil circuit and the requisite zero sharpening effect is obtained by variation of the coupling M.

For sense determination, the aerial loading coil L is disconnected and the open aerial is fed through a phasing resistance R to the potentiometer across the primary of the transformer T_1, the potentiometer being adjusted to give a unilateral diagram.

For stand-by, the potentiometer across T_2 is earthed as in the case of D.F., also the loading coil L is again disconnected and the open aerial is taken direct to the end of the search coil winding as shown. The result of this is to inject a large e.m.f. into the search coil circuit that is in quadrature with the loop e.m.f. so that even if the two are comparable in strength, there will still be a rotating field and less likelihood of an unsymmetrical diagram of reception.

The remainder of the circuit is conventional and includes three R.F. pentode amplifier stages, and a triode detector with triode oscillator circuit for C.W. reception. There follow two resistance capacity-coupled audio amplifying stages, (not shown) with twin telephone jacks.

Grid bias is by potentiometer control from a 10 volt battery. The H.T. supply is 120 volts and a milliammeter with rotary switch measures the anode current of the seven valves. The L.T. loading is 0·8 amp. at 2 volts.

Sensitivity and Selectivity. An attenuation of 6 db. (to 50% voltage) is obtained by a 1·5 kc. detune, and 40 db. (to 1% voltage) by a 5 kc. detune from resonance at 300 kc. (1,000 m.).

Using the aerials shown in Fig. 335, a field strength of 20 μv/m on 1,000 m. will produce a silent arc of approximately 2° when receiving C.W., and of approximately 4° when receiving I.C.W.

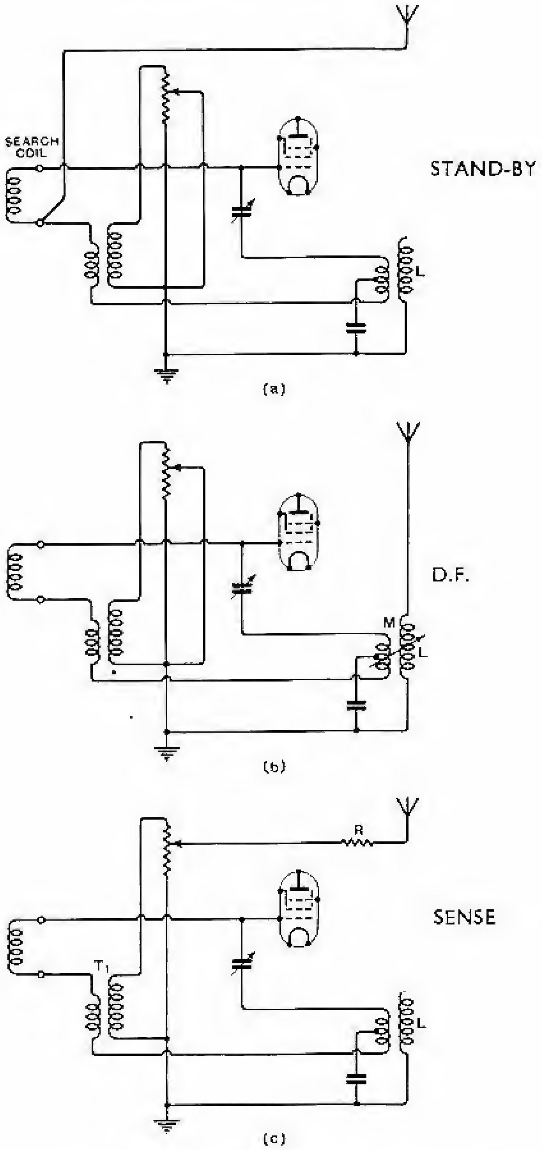


Fig. 367.—Stand-by, D.F. and Sense Circuits.
Marconi Type D.F.G. 11.

CHAPTER 12

BEACON TRANSMITTERS

FOR FIXED COURSES AND FOR LONG-RANGE NAVIGATION

Introduction. In this chapter, and again in Chapter 15, it is proposed to treat the subject of beacons primarily from the viewpoint of the reception of the signals and the methods of using them for navigation, noting the relative merits and possibilities of the systems. Aerial arrays, circuits, diagrams, methods of keying, etc., are mentioned only to the extent necessary to explain the principles of navigation by means of the beacons whilst the extensive subject of the design and maintenance of transmitting equipment is not attempted in the space available.

Some examples of modern beacon apparatus are shown in Chapter 15 and references are quoted, throughout both chapters, to many publications on the development of beacon technique.

INTERNATIONAL REGULATIONS FOR BEACON SERVICE. The bands of frequencies to be used for beacon services and other important particulars are to be found in Section D of Article 30 of the " General Radiocommunication Regulations " that were agreed at the International Telecommunication Convention of 1932.

This Section is reproduced below* but it should be noted that the frequency bands, etc. are liable to revision at the 1938 Convention.†

GENERAL RADIOCOMMUNICATION REGULATIONS, (Art. 30) MADRID, 1932

D. Radiobeacon Service.

§ 13. (1) When an Administration thinks it desirable, in the interests of maritime and air navigation, to organise a radiobeacon service, it may use for this purpose :

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* By permission of The Controller of H.M. Stationery Office.

† See important notice on page 546.

(*a*) radiobeacons properly so called, established on land or on ships permanently moored; their emissions are either circular or directional;

(*b*) fixed stations, coast stations, or aeronautical stations deputed to act also as radiobeacons, at the request of mobile stations.

(2) Radiobeacons properly so called use the following waves:

(*a*) In the European region, for maritime radiobeacons, waves in the band from 290 to 320 kc/s (1,034 to 938 m.), and for aircraft radiobeacons, waves in the band 350 to 365 kc/s (857 to 822 m.), as well as certain waves in the band from 255 to 290 kc/s (1,176 to 1,034 m.) chosen by international aeronautical organisations.

(*b*) In other regions, for maritime radiobeacons, waves in the band from 285 to 315 kc/s (1,053 to 952 m.) and, for aircraft radiobeacons, waves in the band from 194 to 365 kc/s (1,546 to 822 m.).

(*c*) In addition, in Europe, Asia and Africa directional radiobeacons (maritime and aircraft) may use the waves in the bands from 1,500 to 1,630 kc/s (200 to 184 m.) and from 1,670 to 3,500 kc/s (179·6 to 85·71 m.) subject to the conditions fixed by § 20 of Article 7.

(*d*) The use of waves of type B is forbidden in radiobeacons properly so called.

(3) Other stations notified as radiobeacons use their normal transmitting frequency and their normal type of emission.

§ 14. The signals sent by radiobeacons must permit of accurate and precise bearings being taken, they must be selected in such a way as to avoid all uncertainty when there is need to distinguish between two or more radiobeacon stations.

§ 15. The Administrations which have organised a service of radiobeacons accept no responsibility for the consequences of inaccurate bearings obtained by means of radiobeacons in this service.

§ 16. (1) The Administrations notify, for insertion in the List of Stations performing Special Services, the characteristics of each radiobeacon properly so called and of each station deputed to act as a radiobeacon, including, if necessary, the indication of the sectors in which bearings are normally accurate.

(2) Any modification or irregularity in working which occurs in the radiobeacon service must be published without delay; if the modification or the irregularity in working is of a permanent nature, it must be notified to the Bureau of the Union.

LIST OF BEACON TRANSMITTING STATIONS. A comprehensive list of beacon stations appears in the "List of Stations Performing Special Services," published by the Bureau of the International Telecommunication Union at Berne. Details of those useful to shipping also appear in a very convenient form in Vol. 1 of "The Admiralty List of Wireless Stations" (H.M. Stationery Office) and there are, of course, many other sources of the information in the publications of other countries.

Navigational Beacons. For the purposes of this book, it is convenient to divide transmitting beacons into two general classes. The first of these may be termed "navigational" beacons, and with this type bearings can be obtained anywhere within their wireless range. They include :—

(1) The fixed Non-Directive Marine Beacon which enables a ship fitted with D.F. to take a bearing of the beacon *from the ship*.

(2) The Rotating Directive Beacon which makes it possible for the bearing of the ship *from the beacon* to be found, using normal non-directional ship receiving equipment.

These beacons thus become general aids to navigation by providing bearings when and where required, subject to range limits. The bearings are plotted on maps and charts in the same way as astronomical position lines.

Fixed Course Beacons. The second class includes several types, the best-known ones being :

(1) Long Range Equi-Signal Aircraft Beacons (Medium Wave).

(2) Aircraft Approach and Landing Beacons.

Whilst maps or charts are used to check positions when using the long range directive Aircraft Beacons, there is a difference in that the bearings are not plotted in the same way as with Navigational Beacons. The Approach and Landing Beacons are, of course, purely local in application and maps hardly enter into their use at all.

The present chapter deals mainly with the Long Range Fixed Course Beacons. Navigational Beacons are mentioned, together with their organization, but the method of position finding by their means appears in Chapter 14. The discussion of Approach and Landing systems is dealt with in Chapter 15.

FIXED NON-DIRECTIVE MARINE BEACONS

These transmitters, which may be erected on shore or installed in light-vessels, are intended primarily to give, during poor visibility, a service corresponding fairly closely to that provided by light-houses and light-vessels during clear nights, and by distant land marks, etc., by day. The W/T beacons have the disadvantage that their distance cannot be estimated from a single wireless bearing, but on the other hand their range is greater than any visual range and position finding by cross bearings on two or more beacons or by a running fix (page 594) is simple.

When the wireless transmitter has a synchronized air or submarine sound signal, position finding from one beacon becomes possible and is mentioned again on page 596.

Organization of Marine Radio Beacons. The frequency band allotted to these beacons is from 290 to 320 kc. (1,034–938 m.). A few of the transmitters employ C.W. and some are still using spark transmission, but the great majority are modulated. With a view to preventing the dangerous confusion that might otherwise arise due to a random choice of frequencies within the beacon band, of modulation frequencies and transmission times, these characteristics of the beacons of Europe and North Africa are included in a comprehensive scheme.

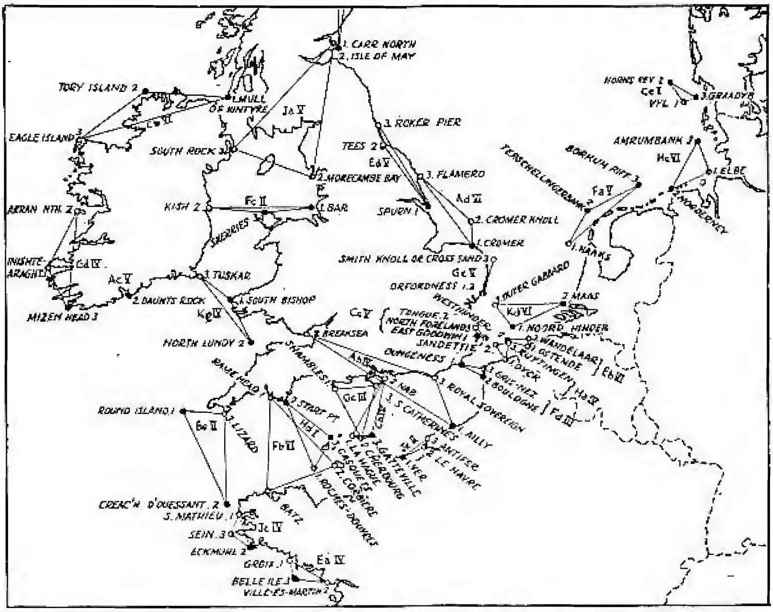

Fig. 368.—Map of Marine Beacons (Working or Projected) of England and Parts of Neighbouring Countries as at Jan. 1st, 1935.

The map*† of Fig. 368 shows the radio beacons and fog signals of Great Britain, Ireland and a portion of the mainland of Europe as at January 1st, 1935, from which it will be seen that the transmitters are in general linked in groups of three, and that the groups are designated by code letters and figures. Thus Roches-Douvres, Start Point and Casquets constitute such a group, are numbered respectively 1, 2 and 3 and the group is " H.d.I.," the meaning of which may be found from the table given below.

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* Adapted, by kind permission, from map published by The Bureau of the International Telecommunication Union, Berne.

† See important notice on page 546.

The numbers 1, 2 and 3 are seen to indicate the times of transmission during fog which are arranged so that they do not overlap. The group letter " H " means that they work on 312·5 kc. (960 m.) ; " d " gives the clear weather transmission times and " I " means that the modulation frequencies may be selected from those of Group I.

Designation of Stations

○ = projected
◑ = in service . . . . transmitting fog signals only.
● = in service . . . . transmitting fog and clear weather signals.

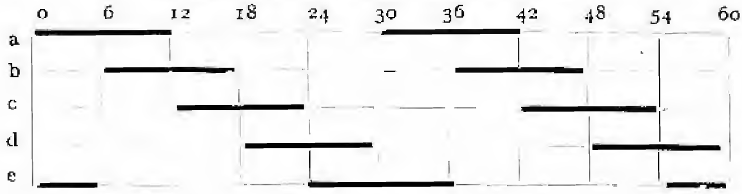
Fog Signal Transmissions

1 = minutes : 0 to 2, 6 to 8, 12 to 14, etc.
2 = minutes : 2 to 4, 8 to 10, 14 to 16, etc.
3 = minutes : 4 to 6, 10 to 12, 16 to 18, etc.

Frequency (waves)

A = 291.5 kc/s (1029.2 m)
B = 294.5 kc/s (1018.7 m)
C = 297.5 kc/s (1008.4 m)
D = 300.5 kc/s (998.3 m)
E = 303.5 kc/s (988.5 m)
F = 306.5 kc/s (978.8 m)
G = 309.5 kc/s (969.3 m)
H = 312.5 kc/s (960.0 m)
J = 315.5 kc/s (950.9 m)
K = 318.5 kc/s (941.9 m)

Clear Weather Signal Transmissions



Frequency of Modulation

Group I	Group II	Group III	Group IV	Group V	Group VI
335 c/s	376 c/s	423 c/s	475 c/s	535 c/s	600 c/s
670 ,,	752 ,,	846 ,,	950 ,,	1070 ,,	1200 ,,
1005 ,,	1128 ,,	1269 ,,			

A study of the groups of beacons on the map, together with their characteristics, will show how well the scheme reduces the chance of mutual interference and of the mistaking of one beacon for another. Certain beacons transmit on C.W. instead of I.C.W. at stated times.

Use of Beacons for Navigation. In making use of these beacons for cross bearings, it is not necessary, of course, to employ only those in one group at any one time. The grouping is to help identification and provided that due regard is given to the range (at night) and to the information concerning the sectors over which good "bearings to" are reported (see page 598), any combination may be used to obtain a wireless fix. The advantage of using the stations of the same group is that no change of tuning is required between bearings, as each linked group is on the same wave length.

An example of their use is given on page 610.

ROTATING BEACON TRANSMITTERS

From the point of view of the ship's navigator, the method of using bearings obtained from rotating beacon wireless transmitters is exactly the same as that in the case of the shore D.F. station, in that position lines are obtained *from* the shore station, and their use for navigation is dealt with in the next chapter.

In 1938, the number of rotating beacons in operation is very small, but they may eventually have somewhat wider application and a description of earlier models may be of historical interest.

General Principles. These beacons possess radiated polar diagrams having either a well defined minimum, as in the case of the loop transmitter type, or a maximum as in those with an aerial array giving a form of beam. By turning the whole aerial system, or by some such means as a radiogoniometer, the polar diagram is caused to rotate at a constant speed and, by the use of an accurately controlled drive mechanism, is arranged to make a complete revolution in, say, exactly one minute.

In such a case the diagram would move through 6° every second and if some indication were given when the zero radiation direction (assuming a loop transmitter) corresponded with true North at the beacon, then by multiplying by 6 the number of seconds that elapse before the minimum sweeps through the receiving point, the bearing from the beacon is given.

The method of indicating the orientation of the beacon during its rotation varies with different systems, but it is easy to see that position lines can be obtained using non-directional receiving apparatus, whilst the standard of accuracy is comparable to that obtained with the ship D.F. and somewhat inferior to that of the shore D.F. station.

TYPES OF ROTATING BEACON

The Telefunken Compass. An early form of rotating beacon transmitter, which never came into common use, employed a series of directional aerials radiating from a single mast which also supported a non-directional aerial as shown in Fig. 369. The method of operating the station was as follows: At pre-arranged intervals, a start signal was transmitted from the non-directional aerial and immediately followed by a series of further signals sent at intervals of one second on each of the directional aerials in turn. There were 32 of these aerials, corresponding to the points of the magnetic compass, and the direction of maximum transmission therefore rotated through a complete circle in 32 seconds and was arranged to start and finish with the direction of North.

All ship stations wishing to make use of the scheme were supplied with a special stop watch which had its dial marked out in the form of a compass, and the " hand " of which rotated once in 32 seconds. If, then, on hearing the start signal the operator started his stop watch and listened until the transmitted signals reached their maximum strength and then stopped the watch, the hand indicated the direction of the transmission at the instant and hence the bearing of the ship from the beacon.

It need hardly be pointed out that the precision of the system was not high, the maximum of the radiated polar diagram of the aerials used being ill defined. Zenneck, however, says that the direction could be found to within 4° or 5° (1501).

This beacon was under test in 1907 and was probably the prototype of the present-day rotating beacons. A patent had, however, as mentioned on page 7, been granted to Marconi in 1906 for a very similar device for directional receiving purposes.

Marconi Rotating Beam Transmitter. An ultra-short wave rotating beacon was developed by the Marconi Company in 1926, using the Franklin beam aerial. A general view of the aerials and reflectors as installed at South Foreland Light House is shown in Fig. 370. The complete aerial system, and hence the polar diagram of radiation, was arranged to rotate at a constant speed and made a revolution in two minutes. During the rotation a series of signals was transmitted, each signal being associated with a certain direction of the beam, so that a ship at sea listening to the signals had only to note what characters were transmitted when the strength was at its maximum in order to be able to plot her bearing from the beacon. This method of operating a rotating beacon has been used in other systems, and has the advantages that a stop watch is not required, and also that, since the signalling contacts are integral with the rotating aerial system, the transmitted signal must always coincide exactly with its appropriate beam direction and the actual speed of rotation is not very important.

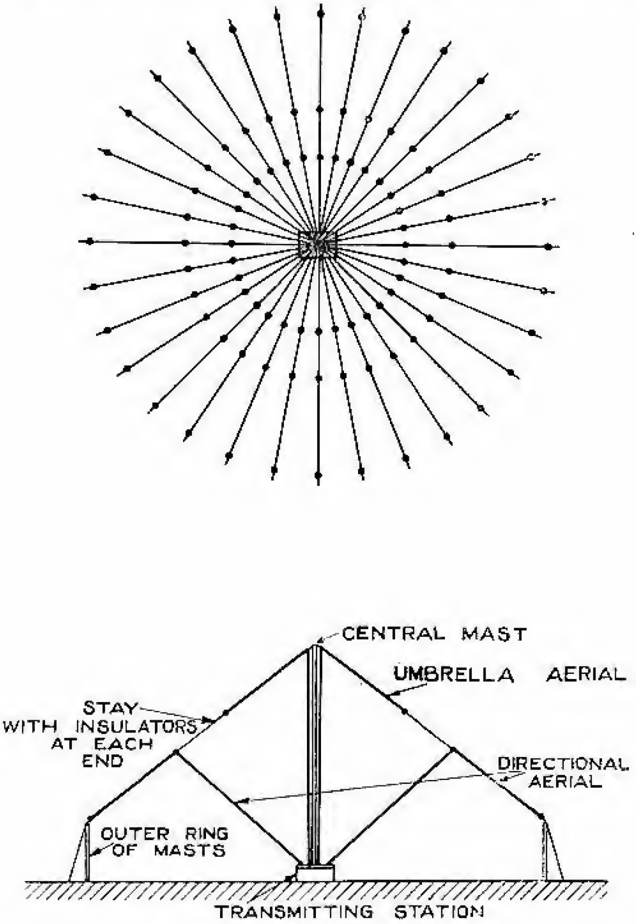


Fig. 369.—The Telefunken Compass.

A disadvantage of this particular beacon was that the wave length used was about 6 m., which made it impossible for ships

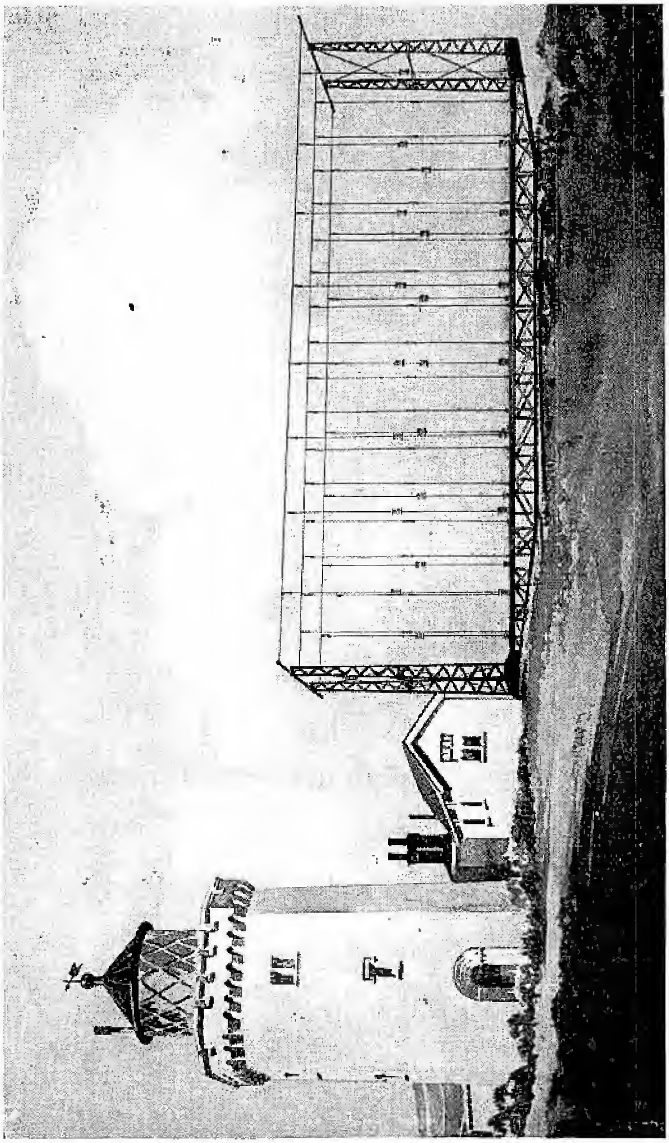


Fig. 370.—Marconi Ultra-Short Wave Rotating Beam Transmitter.

to use their standard receiver, although the special gear required was very simple.

The two lines of aerials were fitted with a reflector between them, the second set of aerials being available, if required, for radiating a second beam in the opposite direction. The method of mounting the array, which was 76 feet long by 30 feet high overall, is shown in Fig. 371.

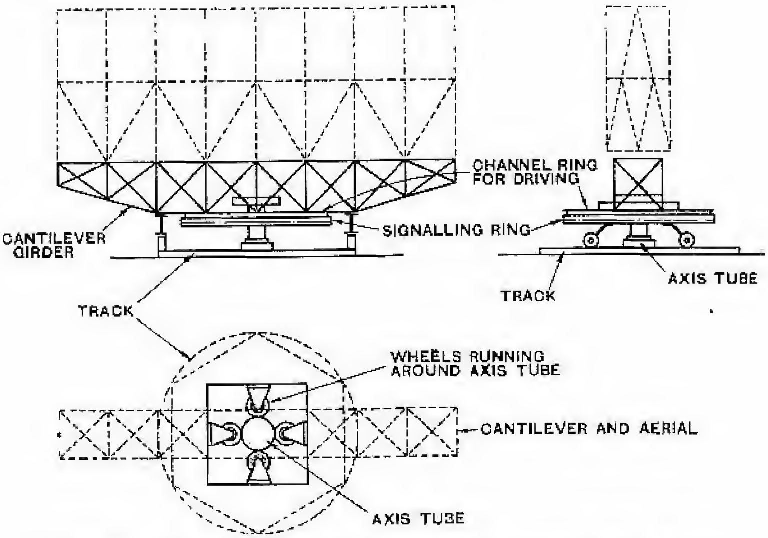


Fig. 371.—Mounting of Aerial System of Marconi Rotating Beam.

The Bellini-Tosi Radiophare. Although the B-T system has been referred to up to the present, mainly with regard to reception, the directive properties of the system are equally applicable in the case of transmitted energy. See various articles by Bellini and Tosi, in the Bibliography and also one by F. Kiebitz (0813).

Later in this chapter there is mentioned a Bureau of Standards use of the transmitting radiogoniometer in connection with their aircraft equi-signal beacons.

R.A.F. Directive Transmitter. The Robinson system has been adapted by the Royal Air Force to directive transmission, whilst still retaining the same distinctive features which are described on page 113 in connection with the directive receiver (2211).

Orfordness Experimental Rotating Beacon. The work on the application of the Robinson frame system to beacon transmission was followed between 1923 and 1927 by further development of the simple rotating loop transmitter, and some of the results were published by T. H. Gill and N. F. G. Hecht (British Air Ministry) in 1928 (2808).

Towards the end of these tests, a similar apparatus was set up by the Radio Research Board at Fort Monckton (Spithead) with a view to checking its performance for marine navigation. This work is described by R. L. Smith-Rose and S. R. Chapman (2809) and the encouraging results obtained during the tests led to the erection of an experimental rotating beacon at Orfordness, on the Suffolk coast. A detailed account of the beacon, with illustrations of the apparatus, is contained in (2805), whilst the following also refer to the work: (3129), (2810), (2811), (3105).

The Beacon Transmission.* The system of signals is illustrated in Fig. 372, where it will be seen that the sequence begins at 45 seconds after the minute G.M.T. and is as follows:

m. s.		m. s.	SIGNAL		
0–45	to	1–45	Call Sign GFP	— — · · · — · · — — ·	Preliminary
1–45	to	1–57	Long Dash	———————————	
1–57	to	2– 0	NORTH Starting signal	· · · — · ·	Signal Group
2– 0	to	2–12	Long Dash	———————————	
2–12	to	2–15	EAST Starting signal	— · · · · · ·	
2–15	to	2–57	Long Dash	———————————	
2–57	to	3–57	Signal Group repeated once		
3–57	to	4– 0	NORTH Starting signal	· · · — · ·	
4– 0	to	4–12	Long Dash	———————————	
4–12	to	4–15	EAST Starting signal	— · · · · · ·	
4–15	to	4–45	Long Dash	———————————	
4–45	to	12–45	SILENT		

Each transmission thus lasts for 4 minutes and successive transmissions are separated by 8 minutes' silence.

Method of Using the Beacon. The principle of the beacon will be clear from what has been said regarding the previous types, but as, in this case, the preliminary and starting signals are sent out on the directive transmitter itself, there would be a risk of an observer being on the zero line for the starting signal if only one were sent. This is the reason for having both East and North starting signals for the stop watch, and these are skilfully arranged so as to aid in starting the watch at the correct instant. In each case after the 12-second dash, a morse signal · · · — or — · · · is sent, depending on whether it is the North or East signal, and following this are two dots before the start. By counting 1 2 3 for these two dots and the start signal, the exact instant of starting the watch can be accurately synchronized.

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*See important notice on page 546.

It is claimed to be possible to estimate the passage of the zero, and to stop the watch correctly, within a fifth of a second, giving an accuracy of $\pm 1\frac{1}{5}°$, whilst an error of two-fifths of a second gives an accuracy of $\pm 2\frac{2}{5}°$ and so on.

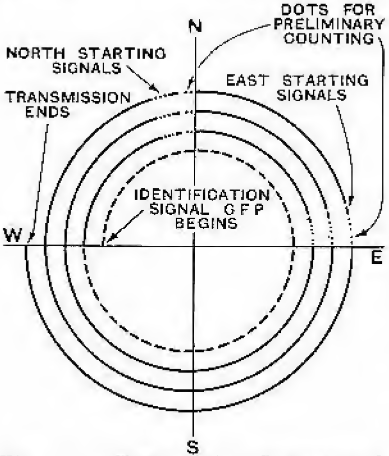

Fig. 372.—Transmission Sequence of the Orfordness Rotating Beacon.
† (Admiralty List of Wireless Signals.)

The bearing can be taken during the first signal group and checked during the second, and work is slightly simplified by using a watch calibrated in degrees, or compass points, instead of seconds, an example of which is shown in Fig. 373 (2811).

The reciprocal bearings due to the two minima of the cosine diagram rarely cause confusion in the case of this particular beacon location.

Summary of Rotating Beacon Features. Some arguments for and against rotating beacons are mentioned below, the bracketed letters referring to the "Ship D.F. *v.* Shore D.F." comparison on page 400.

(1) Interference is reduced as mentioned under (c).

(2) No special wireless receiver is required and the only additional apparatus is a stop watch in certain cases.

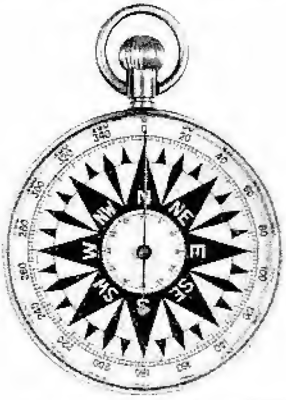

Fig. 373.—Special Watch for Use in Reception of Orfordness Rotating Beacon.

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†Reproduced by kind permission of The Controller of H.M. Stationery Office.

(3) Little skill is required in using the beacon service and the signals are sent in slow morse. Bearings may thus be taken by others than skilled telegraphists.

(4) Mistakes in transmission of the bearing are impossible. See (f).

(5) There is no question of quadrantal error being introduced in the ship and no calibration is needed. On the other hand, night effect is present to the same extent as in other systems so long as a closed loop transmitting aerial is used.

FIXED COURSE BEACONS

The Equi-Signal Beacon

Introduction. Of the various types of directive beacon that have been developed for marine or aircraft use, the equi-signal system has had by far the widest application. The publicity that has been given to the ultra-short wave equi-signal beacons for aircraft approach, and to the attempts to produce a satisfactory landing process during bad visibility, has tended to obscure the less spectacular uses of the system and its interesting early history covering a period of about thirty years.

Equi-signal beacons on medium wave lengths have been used for long range work in this country and elsewhere in Europe, but the largest unified scheme of directive beacons in the world is the U.S. " Radio Range " Equi-Signal Beacon system, the extensive research on which led to the idea of the aircraft landing beam.

The history of these beacons is briefly traced below, together with some notes on the U.S. Bureau of Standards research work and on the use of the beacons for aircraft navigation.

Scheller's Course-Setter. In 1907 a patent was granted to O. Scheller (Lorenz Co.), for a " Course-Setter," the principle of which was as illustrated in Fig. 374. AA and NN are two long horizontal aerials, connected to the transmitting building at O. They are energized so as to radiate polar diagrams, portions of which are marked by the plain and dotted curves, indicating zero radiation at right angles to the lines of the aerials, whilst the remaining portions of the diagrams are cosine or similar in type.

If, now, two easily identifiable signals are transmitted from the two aerials, a ship or other receiver along the line marked " Course " will hear both signals with equal intensity Ox. If, however, the receiver be placed along the line OP, the signal from the A aerials will be heard with strength OP_a and that from the N aerials with strength OP_n, indicating at once that the receiver is off the symmetrical " Course " line.

The Interlocked A/N Signal. Scheller suggested transmitting the Morse letter A · — from one aerial and N — · from the other, the transmissions being so conducted as shown in Fig. 374 that the Morse characters interlock. By this means, whilst the · — or the — · will predominate as the receiver gets further to the one or other side of the course, yet as one approaches the centre line the signals will merge into a prolonged steady note (2903).

Later German Interest. The system had been tried out before the war of 1914–1918 in connection with ships, and in 1917 Kiebitz in Germany made tests on its application to aircraft (2022). He used a pair of crossed horizontal dipoles 140 m. long and intersecting at an angle of 20°. They were supported on a 10 m. centre mast, with 8 m. masts at the extremities. The wave lengths used were 350 and 550 m. At 3½ km. distance, the course had a width of 30 m. on the ground but in the air conflicting results were obtained and the work was apparently discontinued. From the description of the trials by Kiebitz and others it seems probable that most of the trouble arose through polarization errors due to the use of trailing aerials in the aircraft.

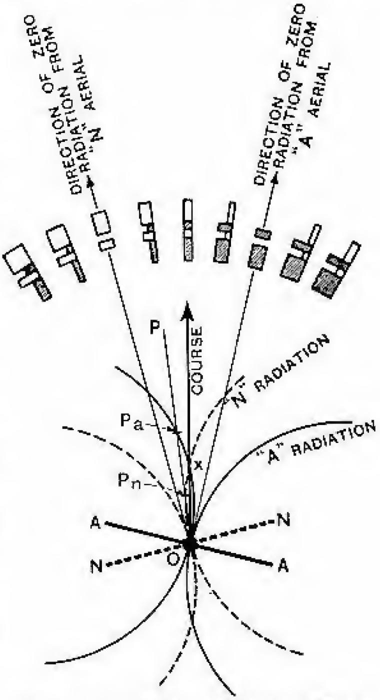
DIRECTION OF ZERO RADIATION FROM "N" AERIAL
DIRECTION OF ZERO RADIATION FROM "A" AERIAL
P
COURSE
"N" RADIATION
"A" RADIATION
Pa
Pn
x
A
N
N
O
A

Fig. 374.—Scheller's (Lorenz) Equi-Signal Course-Setter of 1907, with Interlocked A/N Transmission.

The research was taken up, however, by Buchwald and other workers and with a 150-watt valve transmitter it is stated that aeroplanes at 50 km. distance could distinguish the signals well enough to find their course, whilst on another occasion ships at 85 km. were able to locate a course within 400 m. laterally (2020) (2019).

The U.S. Radio Range Beacon System

A few years after the European War the equi-signal beacon was taken up in the U.S.A. and, as already mentioned, there has grown up in that country a very extensive long range beacon system. Much valuable information can be gained, from the American results, as to the value of these beacons as a method of air navigation and for this reason their development is outlined below, with references to the fuller accounts of the work. The name given to the beacon may require an explanation. When flying a straight course, it is common practice to select two landmarks in line with one another and to use these to hold the course, transferring to other successive pairs of marks as required. Such an operation is called—at least in the U.S.A.—" steering a range " and as the equi-signal

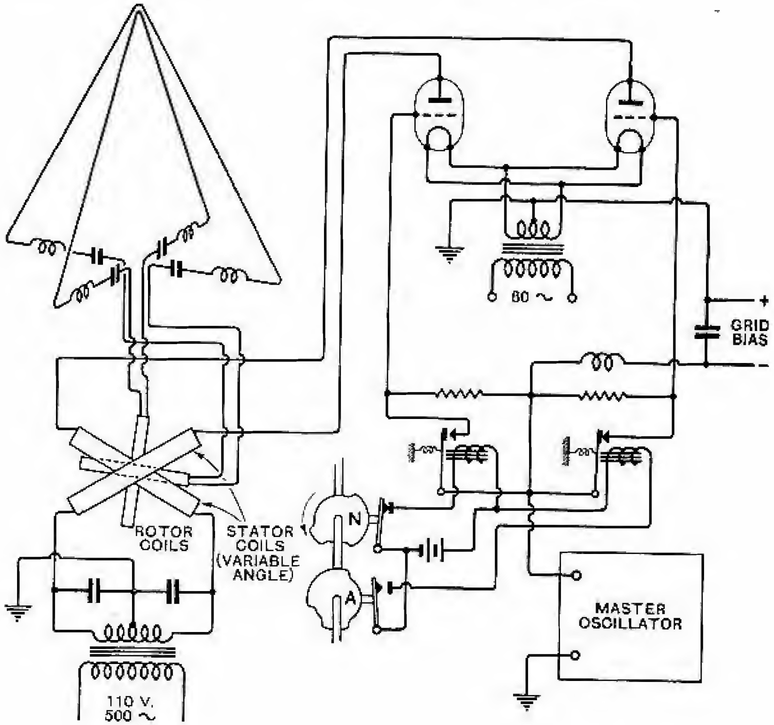

Fig. 375.—Simplified Circuit of U.S. Radio Range Beacon Transmitter. (Bureau of Standards Journal of Research) (Adapted).

beacon performs a similar function the system has come to be known by the above title.

Early U.S. Development. In 1924 a Scientific Paper of the Bureau of Standards described tests with crossed frames and a quenched spark transmitter, in the course of which encouraging results were obtained, the work being carried out in co-operation with the U.S. Signal Corps and the Army Air Service. Ground tests showed a width of equi-signal zone of only 500 feet at 50 miles and interesting effects due to the apparent shifting of the zone with different directions of flight due to trailing aerials, and also the distortion of the course caused by railways, etc. (2405).

From 1923 to 1926, the U.S. Army engineers took up the work and incorporated the interlocked A/N signal and the Bellini-Tosi aerial in order that by movement of the transmitting radiogoniometer the direction of the course could be easily changed (2624).

In 1926 the Aeronautics Branch of the U.S. Department of Commerce was formed and from that time its Research Division, organized by the Bureau of Standards, undertook the task of producing a beacon system for the use of the rapidly increasing number of air routes.

The transmitter adopted is shown in principle in Fig. 375. A 250-watt master oscillator is used in conjunction with two 1 kW. power amplifiers. The B-T type aerials are at right angles and a radiogoniometer is employed to allow of any desired orientation of the courses. The rotor—or what is normally the search coil in the receiving case—here consists of two coils at right angles which are connected to the aerial loops, whilst the two stator windings are in the anode circuits of the transmitting valves, which are alternately keyed in the A/N interlock sequence approximately in the way indicated. The transmission is modulated by the 500-cycle anode supply to the power valves. Since only one of the stator coils is energized at a time, they may have any required angular spacing and a cosine diagram of radiation will be prodnced in space alternately for each stator coil.

A/N Radiation and Course Ambiguity. To avoid confusion, the full polar diagrams were not shown in Fig. 374, but this has been done for the above transmitter in Fig. 376. It will be seen that there are four equi-signal courses which are at 10°, 100°, 190° and 280° in this case, the cosine diagrams being marked A and N to correspond to the signal they represent, and it will also be noted that opposite quadrants are characterised by the same letter.

Note that when flying towards the beacon, the 10° and 190° courses have A to Port and N to Starboard and the 100° and 280° courses the opposite. Flying away from the beacon, however, reverses the indications, so that on picking up a beacon leg there would be complete confusion unless some form of course identification were employed.

Whilst the magnetic compass will help in distinguishing which course is being used, this method, for reasons that will appear later, is not always easy. Tests have shown that it may take an average pilot as long as an hour, when flying in a hooded aeroplane, to get his correct equi-signal course after becoming lost and picking up the wrong one (3318).

The method used latterly for identifying the course on which an aeroplane finds itself, or the quadrant into which it has flown, is described on page 483.

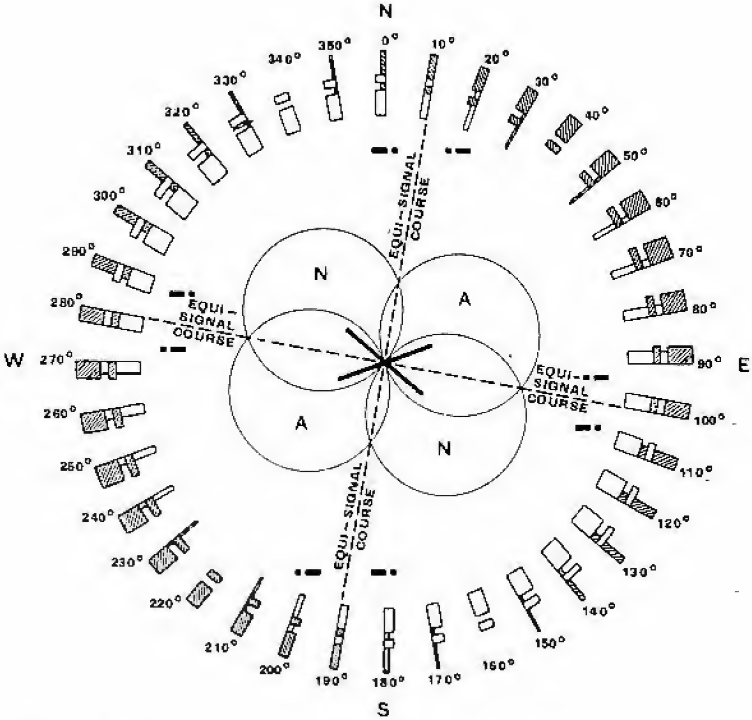

Fig. 376.—Symmetrical Four-Course Equi-Signal Beacon Transmission (Bureau of Standards Journal of Research) (Adapted).

Unsymmetrical Courses. From the map of the U.S. Beacons in Fig. 380, it will be noted that the four courses at any airport are not always symmetrically arranged, since it is necessary that they should be directed towards, and join up with, courses from other airports. The fact that the transmissions on the two stator coils are not simultaneous makes this "bending" of the courses possible in a fairly simple way.

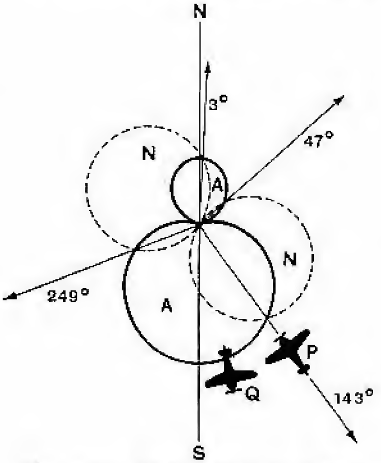

Fig. 377.—Unsymmetrical Four-Course Beacon.

At the centre of the loop aerial system is an open aerial which can be combined with the loops to give any form of polar curve from a slightly distorted figure eight to a true cardioid or an overcoupled cardioid diagram, as in Fig. 54. The stator windings can be adjusted for the required amplitude for each individual cosine diagram and furthermore can be rotated to any required position, so that the alternately keyed polar curves will give equi-signal radiation in almost any desired direction.¶ A combination of a cosine with a distorted cosine diagram is shown in Fig. 377, where it will be seen that the equi-signal courses are on bearings of 3°, 47°, 143° and 249°.

Further U.S. Beacon Research. The work of the years 1926 to 1929 were taken up mainly in the development of visual indicating methods with a view to their superseding the aural method of keeping to the equi-signal course, and though much interesting original work was done few of the results seem to have found their way into practical use.

A Double Modulation system was tried in which the keyed A/N signal was replaced by two steady note frequencies whose relative intensities were shown on a vibrating reed indicator in the aeroplane, the two reeds being tuned to the modulation frequencies.

A large amount of work was done on these indicators with a view to making them immune from temperature changes and also from spurious mechanical vibration (2822), (3009), (3013), (3114), and the principles involved in the production of the desired polar diagrams when using double modulation are of considerable interest (2816), (3011).

A four-course double modulation beacon was next developed together with a method of course and quadrant identification (3318).

This beacon made use of a "course-shifting" method whereby the relative angles of the four courses could be varied to suit the requirements of any given airport (3005). A monitoring device called "The Course-Shift Indicator", working on a bridge principle, was used to show discrepancies in the course direction, due to variation in radiation from either aerial loop, movements of 1° showing up as 1 cm. pointer deflection (2917).

With a view to increasing still further the number of courses of an airport, a Triple Modulation 12-course Equisignal Beacon was next developed, each course being indicated by a different combination of reeds in a most ingenious indicator, with four vibrating reeds and a colour code that corresponded to the various courses (3009), (3013).

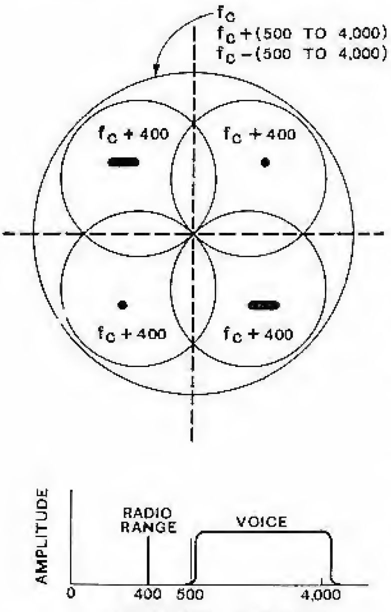

Fig. 378.—Simultaneous Telephony and Radio Range Signal Transmission (U.S. Bureau of Commerce Bulletin).

About 1931 a demand arose for a visual indicating instrument of the "centre zero" pointer type, now in common use in this connection, and a "converter" was produced for application to the vibrating reed indicator whereby the movement of the reed was used to regenerate audio frequency currents which, when rectified, operated the meter. The reeds thus acted as mechanical filters (3113).

This development work, which is described at length in the U.S. Bureau of Standards Journal of Research references quoted, has been referred to briefly for purposes of record, but, as mentioned above, the results were not put into use on the airways' services except on experimental routes.

One of the reasons for the non-adoption of the double and triple modulation schemes was that the number of beacons had grown to such a large number that the cost of equipping them with the necessary modifications to the transmitters was estimated at $500,000 (3422), whilst there is little doubt that the transmitters and also the receiving apparatus, being somewhat complex, would have required careful maintenance. For some years, therefore, the beacons have continued to employ only the aural A/N system.

Simultaneous Transmission of Telephony and Radio Range Signals. The importance of the meteorological broadcasts, and also of the continuity of the radio range signals, was recognized in 1930 and a method of providing such facilities on the double modulation system appeared in 1931 (3117).

A further method of obtaining this simultaneous transmission has since been put forward (3423) for application to existing beacon transmitters. In this process it is proposed to employ two transmitters using the same constant frequency control. One of these works on an omni-directional aerial and radiates the carrier frequency, together with upper and lower voice frequency side bands between 500 and 4,000 cycles. The second is applied to the directive aerial system and uses the upper 400-cycle side band only, as in Fig. 378.

In the aircraft receiver, the +400-cycle side band and the

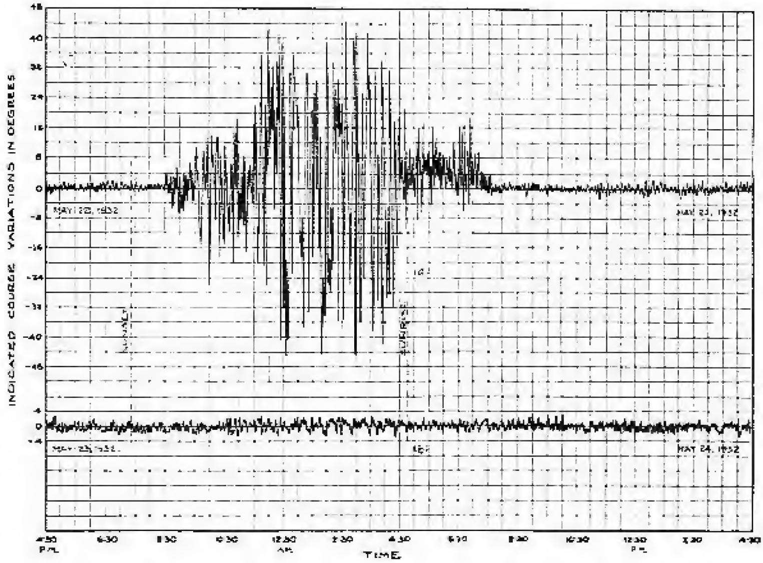

Fig. 379.—Radio Range Course Variations due to Night Effect—Transmission (above) on Closed Loop and (below) Adcock Aerials (Bureau of Standards Journal of Research).

broadcast carrier will beat to give a 400-cycle note, which is passed by a filter network to the audio or visual course indicator. In a similar way the voice frequencies between 500 and 4,000 cycles will be permanently available for weather and other broadcasts.

APPLICATION OF THE TRANSMISSION LINE ADCOCK AERIAL TO THE BEACONS

During the years 1931 to 1934, work was being carried out by the Bureau of Standards on the use of the Adcock aerial for the beacons in order to reduce the errors due to night effect that have been mentioned on page 214 and are illustrated in Fig. 379. The results of this work (3301) were the abandoning of the shielded " U " type of aerial and the development of the transmission line type that has been dealt with, for reception, on pages 247 and 316.

Construction. Four vertical cage type aerials were used, each 75 feet high and composed of six wires round a 4-feet circle. The diagonal spacing of the aerials was 400 feet. An earth system was made round each aerial with plates in two rings of 75 and 100 feet diameter, connected radially. The system was of the coupled type with screened transformer boxes at the bases of the aerials, the leads to the transmitter being ordinary twin conductor 600-volt lead-covered cable buried 18 inches deep.

Synchronization of Aerial Currents. The shape of the radiated polar diagram, being dependent on the phasing of the aerial currents, could be altered easily to provide for special course directions, but it was soon found necessary to stabilize the relative phases of the aerial currents due to the amount of inadvertant course swinging that took place. The need for this may be seen from the fact that a change in capacity of 1 $\mu\mu$fd., in the 500 $\mu\mu$fd. aerials, was enough to give a course shift of 2°, and this was easily produced by the swinging of the aerials in the wind.

The methods used to effect synchronization cannot be explained without a considerable amount of mathematical analysis involving line transmission functions, and the subject passes beyond the scope of this book, but may be studied in the reference quoted above, from which Fig. 379 has been taken.

This diagram shows a 24-hour record on successive days, taken from a point 50 miles from the Bellefonte beacon, and clearly illustrates the effectiveness of the Adcock system in reducing the apparent swinging of the equi-signal course. The reference contains a number of such graphs.

The above reference deals with the phase stabilization on account mainly of reactance changes in the aerials, but the subject is dealt with in greater detail, for both reactance and resistance changes, by H. Roder in (3408).

THE AURAL RADIO RANGE BEACONS IN USE

Course Identification. A map of the beacon system is shown in Fig. 380 and includes more than 100 four-course beacons. It will be realized that pilots must transfer frequently from one range to another, and it is important to be able to identify the courses without the difficulty already referred to on page 478.

In the four-course beacon, the N signal is always assigned to the quadrants through which the True North line passes or, if the course is actually along the meridian, the N is assigned to the adjacent quadrant on the West.

Several times per minute the A/N sequence is interrupted and special identifying morse signals are sent, first on the N quadrants and immediately following on the A quadrants. Thus an aircraft in the position P, Fig. 377, would hear both quadrant identification signals of equal strength, whilst, if at Q, the second or A identification would be stronger than the N, indicating to the pilot merely that he was in an A quadrant. These signals alone are not enough, however, to settle the ambiguity as to which A quadrant he is in, or whether he is flying towards or away from the beacon.

One method of doing this is illustrated in Fig. 381 which shows how the pilot, after ascertaining that he is in an A quadrant, finds his way to the desired leg of the range.

From the aeronautical map carried, the pilot has already identified the beacon itself, found the quadrant identification signals and also the orientation of the courses, so that he knows he is in one of the approximate positions shown in the figure. The procedure is then as follows:

Using the magnetic compass, a course is flown at right angles to the bisector of the quadrant until the equi-signal course is reached. A 90° right turn is now made and if the pilot finds himself back in the same quadrant (in this case A), he knows that he has taken the course marked m^1 and has intercepted the 10° beacon leg. He therefore turns 90° left, until he again enters the equi-signal area, when he turns 45° right and flies along this leg long enough to get a compass reading as confirmation, and then continues or returns to the beacon to pick up another course.

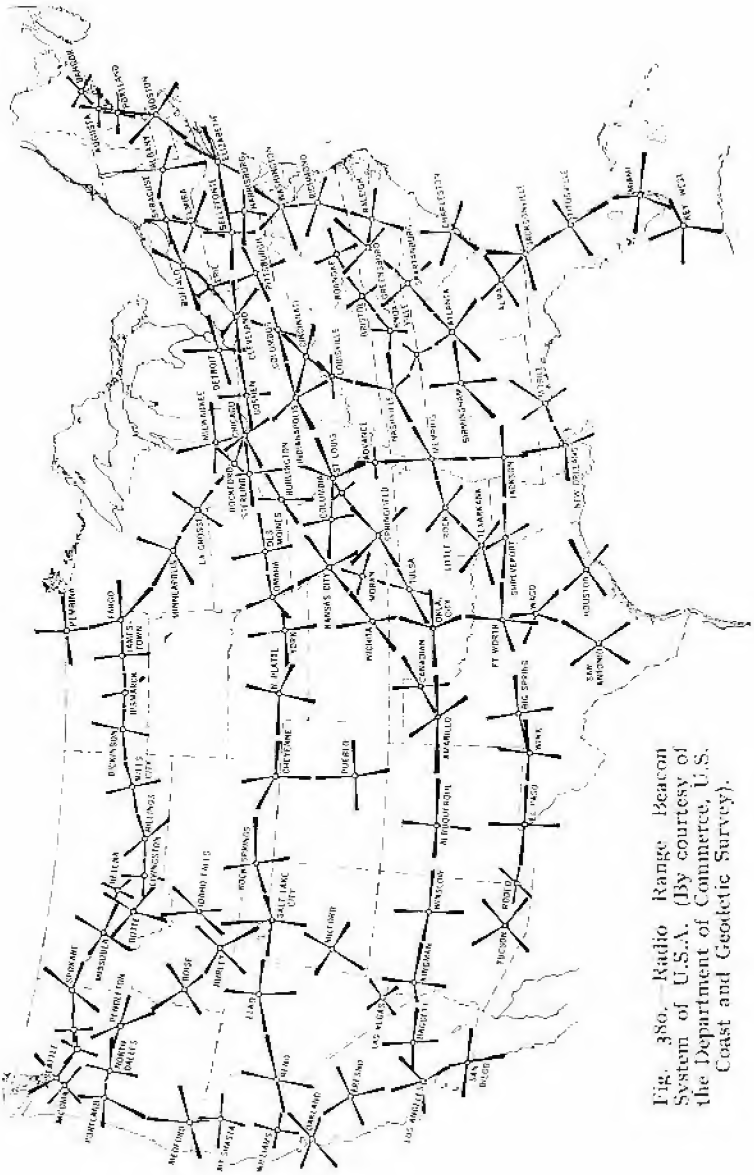

Fig. 380.—Radio Range Beacon System of U.S.A. (By courtesy of the Department of Commerce, U.S. Coast and Geodetic Survey).

Had the 90° turn on first entering the equi-signal zone brought him into another quadrant (N), he would clearly have been on the course m^2, and a further 90° right turn would bring him back to the course which he would check by magnetic compass and so on.

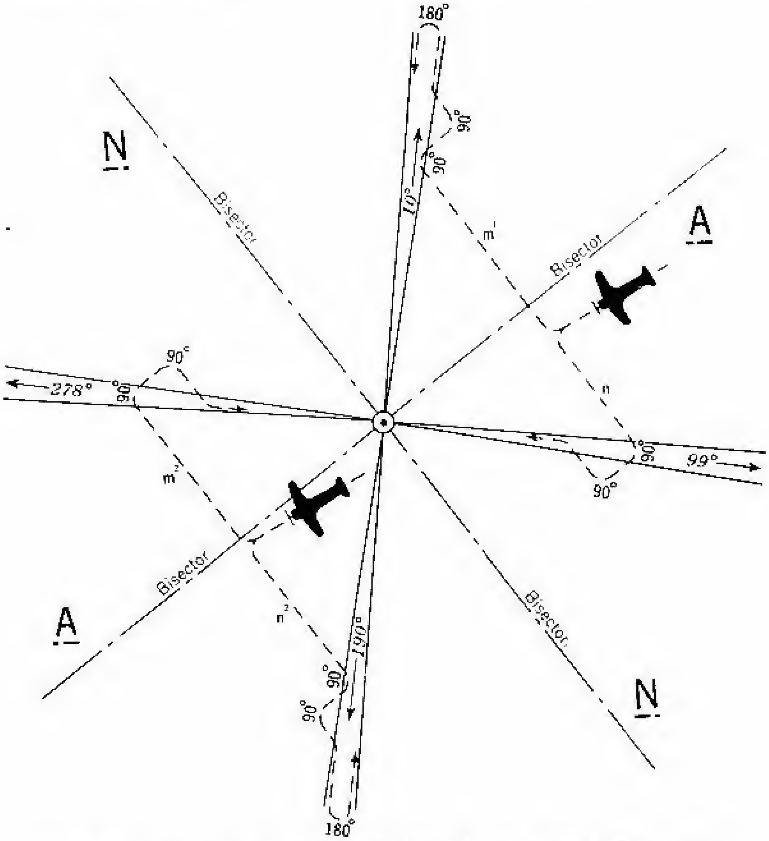

Fig. 381.—Course Identification with Four-Course Beacon (Department of Commerce, U.S. Coast and Geodetic Survey).

Other methods of course identification are used by pilots, though much on the above principle.

Marker Beacons. In order to give information regarding the progress made when flying along a beacon course, low-power transmitters are located at important points. These markers operate on the same wave length as the beacons they serve, and have distinctive signals, reminding the pilot either that he is crossing the leg of another range or that he is approaching the field of a new one in his direction of flight and so should now retune his receiver to the new signal.

Traffic Rules. In order to reduce the chances of collision between aircraft flying in opposite directions along the same range, the " keep to the right " rule is observed as much as possible. This is, of course, not easy, as it involves keeping just off the equi-signal course—a position that is particularly difficult to distinguish aurally, though this should be simpler when a satisfactory visual indicator comes into general use.

The Aural A/N Signal. On first listening to the A/N signal it is definitely confusing, and although the aircraft may be well in an A quadrant, the letter is slightly difficult to recognize automatically due to the monotony of the repetition. For this reason it is found easier by some pilots to use the identification signals as their criterion of how far they are away from the equi-signal course, since in their case they occur during a slight pause in the transmission and the ear is able to recover from the monotony of the interlocked sequence.

The interlocked A/N has been mentioned as being difficult to use when near the course. The 90° and 110° directions in Fig. 376 for instance, have a strong signal with very little contrast between the A and N, and at, say, 95° and 105° the undertone is excessive. The aural dot-dash sequence, mentioned on page 637, is considered more easy to distinguish than the A/N, but it is generally admitted that a good deal of experience is required before the technique reaches the desirable semi-automatic stage.

Use of Flying Instruments. Owing to the spin and turning errors to which an aircraft magnetic compass is subject, its indications are liable to be misleading when carrying out some of the course identification operations mentioned above and a Directional Gyroscope is commonly used in conjunction with it. This instrument shows true azimuth under all conditions and is briefly described on page 619.

The process of picking up an equi-signal beacon course is, in fact, liable to be a source of difficulty to some pilots,and there is a tendency to weave back and forth across the course for a considerable time. This is primarily due to the pilot carrying out too violent a turn when he finds he has passed from, say, the A to the N region and this brings him back across the track again into the A region abruptly, and so on.

The fault can be largely eliminated by the use of a Rate of Turn Indicator in combination with the gyro. (which shows the amount of turn) but there is the disadvantage of having yet another instrument to watch in the process. A very real difficulty nevertheless exists in this respect and is mentioned again on page 619 in connection with approach beacons.

CRITICISMS OF THE RADIO RANGE BEACON SYSTEM

The principal claim for the radio range beacon system is that it is well suited to the overland routes between widely separated cities, where air traffic is continuous and where ground D.F. stations would become choked with requests for bearings in periods of bad visibility. In the main, these requirements are well met by the radio range system, but criticisms have been levelled at many of the shortcomings that have shown up in the operation of the beacons, and some of these are mentioned below.

Control of Aircraft. The combination of telephony with the range signals not only ensures weather reports and other important matter being received by all aircraft in the neighbourhood, but, in addition, the telephony channel and continuous course indication are said to add a feeling of security that is not present when navigating by isolated bearings from a ground station.

This feeling of security is, however, rather discounted by the knowledge of night effect, split courses and fading, mentioned below, whilst the lack of control by, or contact with, a ground D.F. station is also considered a disadvantage in that an undue amount of responsibility is thrown on the pilot when he gets into difficulties. Thus an incident has occurred of a distress call being received from a pilot flying a radio range course, saying he was being forced down due to ice and did not know where he was. Due to the absence of ground D.F. service, no one else knew his position. The aeroplane landed in a forest clearing in deep snow with some damage to the passengers and craft, and was fortunately found forty-eight hours later.

Fixed Routes. The fact that the beacons operate along fixed routes, leaves nothing available to the independent itinerant flyer, unless he carries homing or D.F. apparatus in his aircraft. The advance in the development of this apparatus in the U.S.A. is probably due to this cause. The concentration of traffic along certain routes also increases the chance of collision, in spite of the general rule to keep to the right of the beacon course. Co-operation between air line companies in the matter of agreement to fly at definite altitudes helps in this respect, but has the disadvantage that there is at times an optimum altitude at which to fly, on the score of visibility, ice formation, and also passengers' comfort in bad conditions.

Location of Beacons. Since cross bearings (page 550) are not an essential part of the system of navigating, the radio range beacons may always be situated in the neighbourhood of the airports which, in thinly populated areas, has much in its favour.

Interference. The continuous transmission of modulated signals leads to considerable interference and the matter has already caused the authorities some concern. Confirmation of the existence of this interference is provided by the specifications of certain American receivers for marine use, in which the extent to which the airways' beacons can be eliminated is sometimes mentioned as a feature. Conversely the beacons themselves are jammed by the W/T services, though this is a fault in organization of wave bands rather than of the radio range system.

Night Effect and Split Courses. Although night effect has been much reduced by the use of the Adcock aerial on a number of the beacon transmitters, residual errors are still found to exist. In addition to this, certain beacons, due to the nature of the ground, exhibit spurious equi-signal courses which may remain steady and so be mistaken for the true course. These split courses can at times be observed when flying across a beacon leg, A and N regions being traversed several times in succession.

When flying towards the beacon, either of these effects may be very misleading, but when flying in the opposite direction, the pilot may finally come to the end of the equi-signal course he has been following and become totally lost. Still more important is the fact that both split courses and night effect are more marked in mountainous regions, and an aircraft may, under these conditions, crash into the side of a mountain when completely unaware of any obstructions. Such incidents have actually occurred, but the danger is reduced by the marker beacons mentioned above. Failure to hear a marker when expected indicates that the wrong course is being followed.

Fading Signals. The disappearance of the beacon signal when the aeroplane passes over the transmitter is commonly taken as an indication of arrival at the port, and when flying over cloud or fog the aircraft will then request permission to descend through the cloud and land if conditions are satisfactory. Due again to mountainous country and to propagation effects, beacon signals may at times be so weak as to lead the pilot to assume he is over the transmitter, and one bad accident is reported to have occurred due to permission to descend being given to a pilot when the aircraft was fifty miles from the beacon and over high ground with poor visibility.

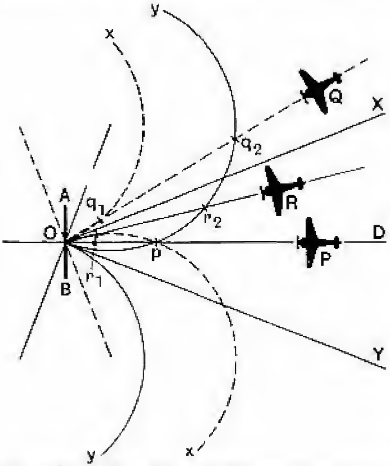

Fig. 382.—The Aicardi Beacon System.

Summary. Whilst the idea of a network of equi-signal beacons covering a country may appear attractive, there are thus very many problems to be worked out before it can become entirely satisfactory. Solutions are being found for many of the weak points mentioned in this rather formidable list, and in any case there remains the fundamental advantage of a beacon system, over a ground D.F. system, namely the absence of a flood of requests for bearings when flying conditions become difficult. This makes perseverance with the system worth while, once the beacon method has been decided upon as best suited to an area.

It nevertheless appears that the future of the equi-signal beacon lies less in long-distance work than in its increasingly popular application to approach and landing methods, and these are dealt with in a later chapter.

THE AICARDI SYSTEM

This system may be included under the heading of rotating beacons, in that the directive radiation rotates—or rather oscillates—to and fro through an arc of a circle.

In Fig. 382, AB represents a frame aerial, with space pattern of radiation such that the zero line will be along the line OD, on which it will be supposed it is required to direct the flight of an aeroplane. Apart from the unsatisfactory nature of a flight on a null signal, there is also the uncertainty as to which side of the course the aeroplane is, when off course, and also by what amount. To avoid these defects of the simple homing method, the following changes have been made in the transmitter.

Firstly, the frame is made to oscillate at constant speed through an angle of about 10° on either side of the course direction, say 10 times per minute, so that the line of zero signal has the extremes shown by the lines OX, OY. Secondly, the modulated note of the beacon is momentarily changed every time the zero line passes through the direction OD on the clockwise swing from X to Y, but not on the return swing from Y to X.

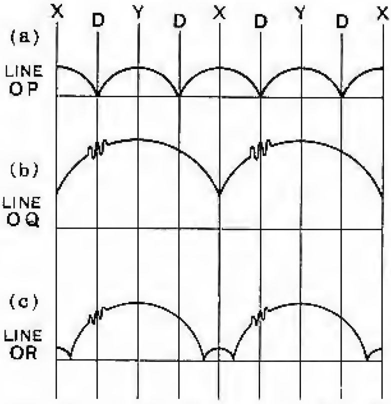

Fig. 383.—Signal Sequence of Aicardi Beacon for Directions shown in Fig. 382.

An aeroplane in the position P will thus hear a sequence of signals as shown in Fig. 383 (*a*), during two complete swings of the frame. When the zero is along OX as indicated by the dotted polar diagram x/x, a signal proportional to Op is heard along OD, falling to zero at the mid-point of the swing, rising to Op again when the zero is along OY and similarly on the return swing. This symmetrical spacing of the zero, without hearing the change of modulation, corresponds then to the "on-course" direction.

For an aeroplane at Q, the signal is of strength q_1 when the zero is along OX, increases to q_2 when the zero is along OY and returns to strength q_1 again, without extinction but with an audible change of modulation, Fig. 383 (*b*). The fact that the signal does not fall to zero indicates that the direction OQ is outside the limits OX-OY, and since the change of modulation follows the instant of minimum signal by about a quarter of a period, the receiving point must be on the X side of the course —since the modulation change occurs only on the swing *from* X to Y.

An aeroplane at R will hear the sequence, Fig. 383 (*c*), where the strength for the X direction of the zero signal is given by r_1, then falling to zero as the zero sweeps through the direction OR. The change of modulation is heard a little later as the zero passes through the OD direction, after which signals increase to r_2 corresponding to the OY limit. They now begin to fall again to a zero, followed by a slight increase to r_1 again at the end of the swing but without any modulation change. The continuous sequence thus has two zeros close together, followed by the modulation change, indicating that the receiving direction is within the arc of swing of the beacon and on the X side.

In practice, the swinging of the zero is done electrically, and not by means of a moving frame. In tests using a 60 m. wave, two vertical aerials were used, one radiating a steady C.W. signal and the other a weaker modulated signal on the same fundamental frequency. The space pattern of such a system can be arranged to be similar to one of the series of Fig. 58, having well defined zero values and the remainder of the diagram depending on the aerial spacing.

The swinging of the zero line was produced by a mis-phasing of one aerial current due to a rotating condenser, with which was ganged the switch for changing the modulation note at the required instant.

Tests were carried out on ships at Havre in 1927, and also on aircraft at Saint-Cyr, and it is claimed that a precision of the order of 1° at 60 to 80 km. is possible (3016) (2927).

A direct reading indicator has been devised for use with the Aicardi system, using lamp signalling.

THE LOTH SYSTEM OF ROTATING BEACONS

This system, which depends for its action on the intersections of the directive " beams " from two rotating beacons, was introduced as a substitute for the leader cable.

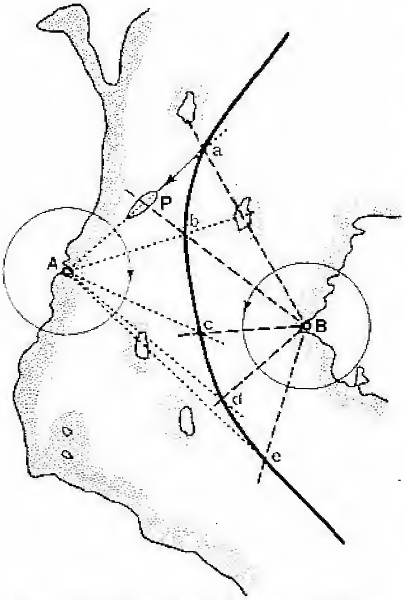

Fig. 384.—The Loth System of Twin Rotating Beacons.

In Fig. 384, A and B are two rotating beacons, the speeds of rotation of which, instead of being constant, are variable and so coordinated that the directions of the minima always intersect along the desired route. One beacon—A in the diagram—transmits dots and the other dashes, and a ship fitted with ordinary non-directional receiving apparatus, when on the route, always hears the signals from the two beacons disappear simultaneously. If the ship gets off the course to a point P, then being at the " a " direction of minimum from the beacon A but the " b " direction from beacon B, the dot signal zero will be heard before that of the dash, indicating " off course " on the A side.

A somewhat unique quality is that by suitably varying the speeds of the beacons a curved route can be provided, which might have useful application in marine navigation but less so in aircraft work, for which purpose the system is also put forward by the inventors.

Considerable discussion has occurred over the virtues of the system, some of the alleged disadvantages of the scheme being that owing to the difficulty of determining the exact instant of the passage of the minimum, the breadth of the route becomes excessive, though it is stated in reply that by the use of a special form of receiver, this difficulty can be largely overcome (3002) (3108). This, of course, introduces the further point that standard receiving apparatus is at some disadvantage. The system is also criticized for its inaccuracy unless a long base line is adopted between the beacons, also for the difficulty of applying it to the operation of a number of air routes, its comparatively short useful range for aircraft work and its susceptibility to night effect.

In reply to some of these criticisms, it might be pointed out that any system which relies upon cross bearings naturally requires a long base between stations—this also applies equally to the aircraft ground station. With regard to night effect, the Adcock principle appears to be applicable on the same lines as those adopted by the U.S.A. Bureau of Standards for their Equi-Signal Beacons.

Extensive tests have been carried out with the system in France (2921) (2922) (3016) (3004).

CHAPTER 13

THE AIRCRAFT D.F. INSTALLATION

The Problem of Aircraft Navigation. It is fairly true to say that all the problems of the ship D.F. installation are repeated in an exaggerated form when an attempt is made to navigate an aeroplane by means of a D.F. fitted in the machine, and additional difficulties are also encountered which have heavily taxed the ingenuity of those engaged in this application of direction finding.

Amongst the factors which militate against accurate working are the cramped space in which the wireless apparatus usually has to operate, ignition circuit interference, the prevailing noise, the urgent need for reliability combined with minimum weight and the speed with which bearings must often be taken and decisions made due to the high speed of the machine. In the case of an actual D.F. installed in an aeroplane, as distinct from homing equipment, there is also the difficulty of fitting the rotating loop in such a site that it may be conveniently used and will at the same time be structurally safe and will enable a reliable calibration to be maintained.

In the early days of D.F. in aircraft, internal rotating loops were employed although the interior of the fuselage of the aeroplanes then in production was probably one of the last places in which a rotating frame could be expected to record accurate bearings of distant stations. The proximity of the engines and tanks introduced screening and, in addition to this, the whole machine was a network of wire stays, struts, controls and electrical wiring, including the ignition system of the engines. These not only produced a large number of closed metallic loops in various planes but also gave the aeroplane the characteristic of the hull of a ship and produced definite quadrantal errors of the same nature, having their minimum values fore and aft and thwartships.

With certain designs of aeroplane which made considerable use of wood and fabric, the rotating fuselage coil gave fair results, but with the increasing tendency towards metal construction, the small fuselage coil became so screened and was working in such a complex electromagnetic field as to be useless for accurate working.

Rotating loop aerials are now almost universally fitted externally and are in some cases designed to be withdrawn when not in use.

Operation of the D.F. Gear. The problem of who is to operate the D.F. apparatus in an aeroplane naturally exercises a great influence over the design of the gear. On the one hand it may have to be of the simplest kind for use by a private owner-pilot, whose mind is liable to be fully occupied when difficulties arise due to thick weather and whose knowledge of the Morse code or even of W/T may be very limited. In such a case even a simple homing system may offer difficulties. On the other hand, in the largest air liners, the crew includes an expert telegraphist and a navigator and the conditions approximate to those in a ship, so that comparatively intricate gear can be installed with complete confidence.

D.F. Systems Used in Aeroplanes. Directional systems of reception installed in aeroplanes for navigation between airports, as distinct from approach systems or the use of directive beacons, are limited to two types, or modifications of them, namely:

The Homing Device with Fixed or Adjustable Loop.

The D.F. with Rotating Loop (or Bellini-Tosi Aerial).

The principle of the aircraft D.F. does not differ from that of the ship D.F., though the details of the design will be seen in subsequent examples to be considerably modified to suit the new demands of extreme lightness combined with the ability to withstand shock, and also the necessity for remote control to simplify the accommodation of the apparatus.

The homing system, however, introduces principles that are not common to marine work.

A knowledge of the principles of position finding by cross bearings has been assumed and if necessary this chapter should be read in conjunction with Chapter 14.

THE HOMING PRINCIPLE

In its most elementary form, this consists of heading the aeroplane towards a transmitter at the objective, any deviation from this course being indicated by a change in strength of the received signals. The aerial is a loop, fixed so that its plane lies at right angles to the fore and aft line of the machine, and, provided that everything is in order, a zero signal indicates that the transmitter is in the direction of one of the cosine minima of the loop, namely, exactly ahead or astern.

The Wing Coil. One of the earliest coil systems was developed as a substitute for the small rotating loop inside the fuselage, which, with inefficient ignition screening in the early engines and the distortion of bearings due to the adjacent metal work, was difficult to use with any degree of assurance. The suggestion was to have the aerial loop secured to the wings as shown in Fig. 385 and the aeroplane was swung in order to take bearings. An area of coil of 100 to 150 square feet could be obtained in this way without difficulty, and the signal to noise ratio was greatly improved.

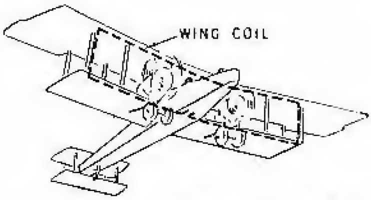

Fig. 385.—Early Form of Wing Coil.

The Fixed Fuselage Coil. This was a development of the wing coil, the smaller homing loop attached to the surfaces of the fuselage being made possible by the increasing sensitivity of receivers and the progress in the screening of engine ignition systems. The device is now falling into disuse owing to the advent of loops of small diameter which are in some cases enclosed in streamlined housings and mounted externally to the fuselage. The fuselage loop is, however, still to be found in service and it has been used, with success, in aircraft with metal skins. In this latter case, freedom from the effects of the metal structure is obtained by mounting the coil round the nose of the aircraft and standing it off on spacing blocks. It is necessary in such a case, however, to bear in mind regulations regarding the rigging of aerials forward of the propellers.

An experimental loop of the above type is shown in Fig. 386.

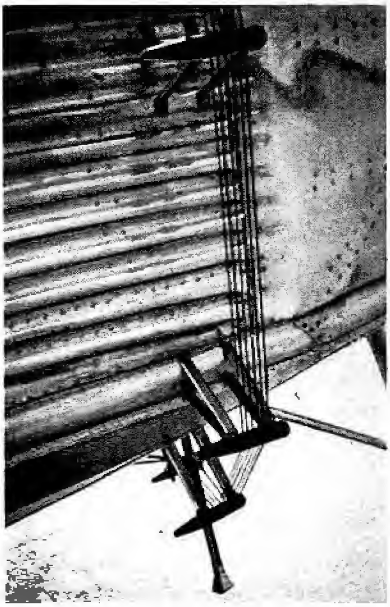

Fig. 386.—Experimental Fuselage Coil Over Metal Skin.
(Imperial Airways Ltd.)

DRIFT AND ITS EFFECT ON A HOMING COURSE

The effect of drift on an aircraft when flying a compass course is well known and allowance can be made in a simple way. Its effect upon a homing course is less straightforward, and when a cross wind is blowing the use of a homing device has certain limitations. In Fig. 387 the air speed of the aeroplane and the wind velocity being represented by the vectors OA and OB, the ground speed of the aeroplane will be a combination of its air speed and the wind velocity as represented by the vector OC. The important point to notice is that the machine does not now head in the direction of the actual course followed.

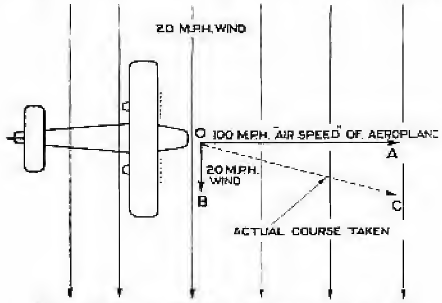

Fig. 387.—Drift of Aeroplane due to Wind on the Beam.

In these circumstances, the use of a homing device results as shown in Fig. 388. At (*a*) the aeroplane is taking the correct course for flying direct to the objective, namely, heading slightly into the wind or crabbing. If, now, the aeroplane be headed, by a homing device, straight for the transmitter as at (*b*), then the wind will cause a drift to some position (*c*), when the course will again have to be altered to bring it " head on." This process continues until, depending on the wind velocity and the duration of the flight, the aircraft may actually approach the objective eventually flying up wind as at (*g*).

Time Lost Due to Drift when Homing. It is important to notice that when heading into the wind to a sufficient extent to correct drift, as shown in Fig. 388 (*a*), there is a loss of ground speed that will become greater as the ratio of wind speed to air speed increases.

In these notes it is assume for simplicity that the wind is on the beam.

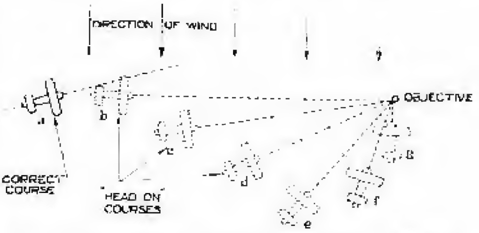

Fig. 388.—Effect of Drift when Flying Head-On to Transmitting Station Beacon.

As a result of this, the time lost by ignoring any correction for drift and following the curved course of Fig. 388 is surprisingly small and this course is normally employed by aircraft equipped with a simple fixed transverse loop.

Fig. 389 shows the times taken for the shortest route and the simple homing route for various wind speeds. It will be noted that for a 100-mile journey, with an air speed of 180 miles per hour and a cross wind speed of 30 miles per hour, the difference in time is only about half a minute. A slower aircraft with an air speed of 120 miles per hour in a cross wind of 50 miles per hour is delayed 6½ minutes, corresponding to a 10% increase in time.

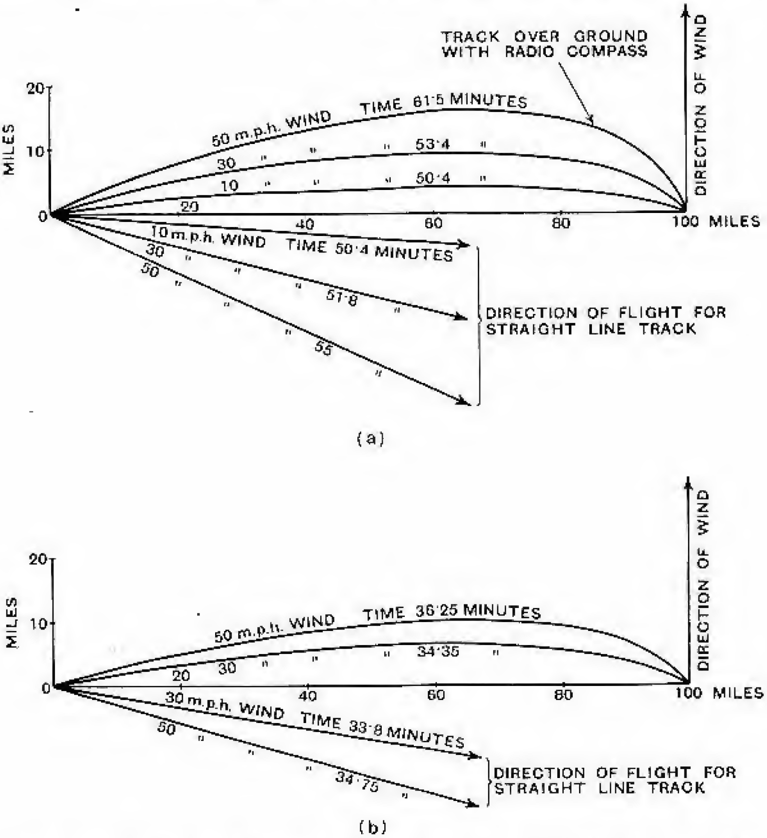

Fig. 389.—Time Lost due to Drift when Homing. Air Speed (*a*) 120 m.p.h. (*b*) 180 m.p.h.

Advantages of Correction for Drift. So far it has been assumed that the homing transmitter is situated at or near to the point to which the flight is being made, but such is seldom the case. Fig. 390 shows an aeroplane employing a transmitter B in line with the objective A but at about twice the distance. In such a case the uncorrected homing course will result in the aircraft passing the point A at a considerable distance, and a choice of a transmitter at some point C, if available, would be preferable, though if the aircraft were able to maintain a straight course it would be a great advantage.

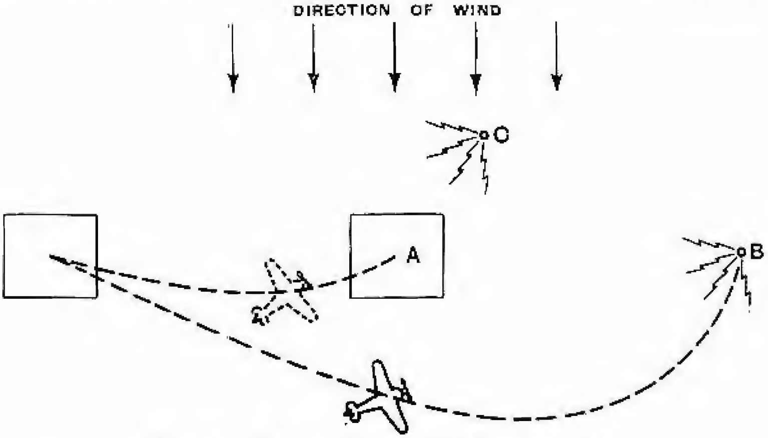

Fig. 390.—Choice of Beacon for Homing Flight.

There may be actual danger in certain circumstances in flying an uncorrected homing course, and particularly in a country such as the U.S.A. where equi-signal beacons are available. These beacons are, of course, primarily intended for the use of aircraft making use of the directive transmission and flying along the proper " lane," according to whether they are approaching or receding from the beacon.

An aeroplane using one of these beacons for homing with an uncorrected curved course, and ignoring the directive properties of the transmitter, is very liable, owing to drift, to be carried across or into the " lane " allotted to craft travelling in the opposite direction, which will cause some confusion at any time and danger in thick weather.

EXAMPLE OF CORRECTION FOR DRIFT WHEN HOMING

A homing flight is to be made from A, in Fig. 391, to the beacon at P, the air speed of the aircraft being 150 m.p.h. and the wind E.N.E. with a velocity of 30 miles per hour. The required course is found to be 54° magnetic.

It is assumed that the loop is rotatable and so can be adjusted for drift, but that in this case a start is made with no drift allowance, that is to say with the loop set at 360° scale reading, and centre pointer on the visual indicator. (Homing apparatus with visual indicator is described later in the chapter.)

After flying for 15 minutes, it is observed that the compass reading is 57°, showing that the aircraft is off course to the West, as shown in the diagram, where Ab is the air speed vector and bB the wind vector. It is decided to make a drift allowance of 10° and, since the course to P is now 57° mag., the aeroplane is headed 57°+10°=67° and the loop slightly rotated to centre the pointer of the visual indicator.

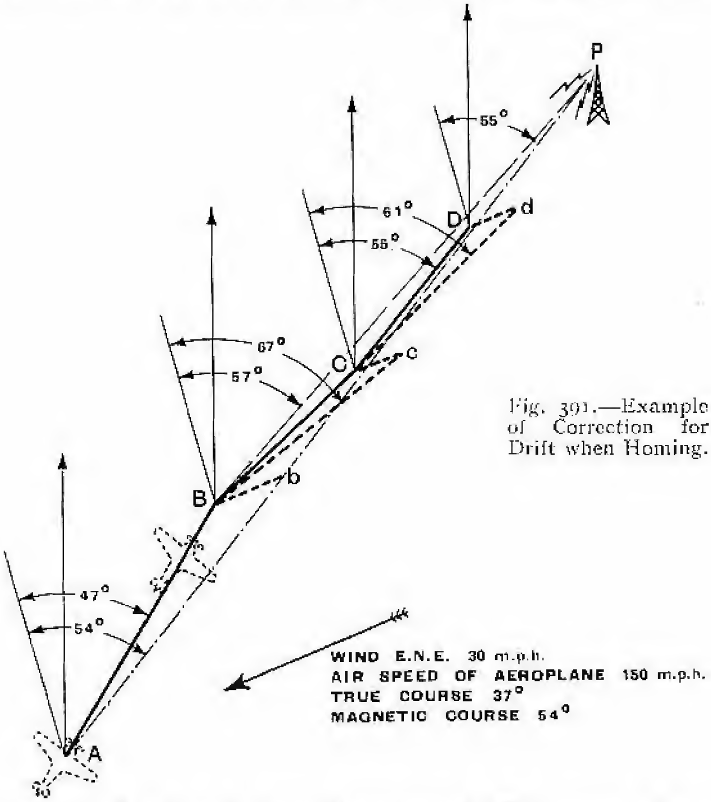

Fig. 391.—Example of Correction for Drift when Homing.

After a further 10 minutes' flight under these conditions, the aircraft is again headed for the beacon by bringing the loop back to 360° with centre pointer reading when it is noted that the compass reading is 55°, or less than before, indicating a deviation to the east of the new course as shown by the position C and the vector triangle BcC. The drift allowance is now reduced to 6°, making the course 55°+6°=61° mag., and a check after another 10 minutes' flying shows the course (from the new position D) to be still 55°, the 6° allowance having been correct.

In the case of the example taken, the beacon will be reached in such a short time that further checks will be unnecessary, but, on a long flight, changes in the velocity or direction of the wind may occur so that a drift correction must not be used for very long without checking for change of magnetic course in the manner described, making proper allowance for change in magnetic variation when necessary.

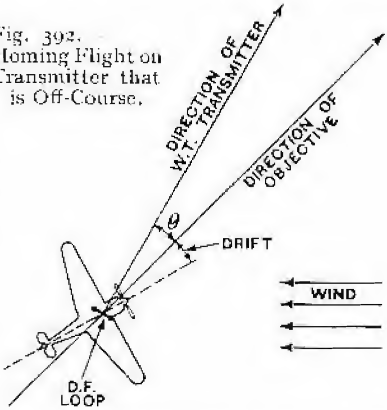
Fig. 392. Homing Flight on Transmitter that is Off-Course.

The advantage of this combination of homing device and magnetic compass is that it enables a straight course to be kept in varying wind conditions, when there is no opportunity to check the drift by visual means.

Suggested Automatic Drift Correction. From Fig. 391 it has been seen that as the aircraft varies from its course to positions B, C, D, etc., the magnetic compass reading also changes and, assuming steady wind conditions, the maintenance of a straight course could be ensured by keeping the magnetic compass on a prearranged course and the radio compass (see page 505) always at the equi-signal position, the loop having been set for the drift angle.

There is described in (3304) a method of keeping an aeroplane automatically on a straight homing course by electrically connecting the two compasses. So long as the magnetic compass reads its pre-set value, a condition of balance is maintained, but if the reading varies—indicating drift—the rudder is operated by the unbalance current of a type of bridge circuit, and at the same time the loop is adjusted to a new drift angle so as to maintain the new course to the beacon.

Off-Course Homing. When no transmitter is available at or in line with the objective, and it is desired to fly a straight course, a common expedient is to make use of a transmitter that is within, say, 10° or 20° of the desired course and preferably at a long range.

In order to do this it is necessary to set the loop so as to allow for both drift and also the angle between the transmitting station and the objective, and Fig. 392 shows the loop set so that the zero on the transmitter is at the sum of these angles.

Unless the transmitter is at a great distance, the angle θ will require further correction as the flight proceeds, but the method is widely used.

EQUI-SIGNAL HOMING

When homing with a simple transverse loop, a zero signal normally occurs when the correct course is being maintained, and there still remains the tedious operation of swinging the machine slightly in order to ensure that the signal is still there and that a central course is being steered when the arc of inaudibility is fairly wide.

To avoid this, Scheller's equi-signal system, which has been described in the previous chapter in its application to the transmitting beacon, has been applied to the homing receiver, in order to provide a constant check that the course is being kept, without the necessity for swinging off course.

If, in Fig. 374, the two lines AA, NN be considered to be receiving loops fixed in an aeroplane, so that the line marked "course" is along the centre of the machine, then, for a transmitting station dead ahead, signals will be received with strength Ox in each loop. If the aeroplane be turned off its course to starboard so that the transmitter is along the line OP, the relative strengths will be OP_a and OP_n. If, therefore, the receiver be switched from one loop to the other this provides a method of maintaining a head-on course.

There are various pit-falls in this system as in the case of flying on an equi-signal beacon course, and care has to be taken as far as possible to eliminate sense ambiguity and errors due to overloading of the amplifier as the transmitter is approached.

The Robinson System. The Robinson system was originally introduced as a form of equi-signal direction finding, which gave ample signal strength throughout the operation, as distinct from working on a cosine minimum alone. Such a system had obvious advantages when ignition interference was still a severe handicap to reception.

In this system (which was described on page 113) it will be remembered that the signal is received by the smaller or "main" coil at maximum strength, and by the larger or "auxiliary" coil at minimum strength, and the auxiliary coil is switched in series with the main coil, alternately in one direction and the other. The figure eight minimum is thus superimposed on the almost steady signal from the main coil, and the direction found by getting the auxiliary coil exactly in its minimum position. The possibility of a 90° ambiguity was avoided by observing the positions of the two minima by putting the reversing switch first in one position and then the other.

It was later adapted to wing coil working as in Fig. 393, and so became an equi-signal homing system.

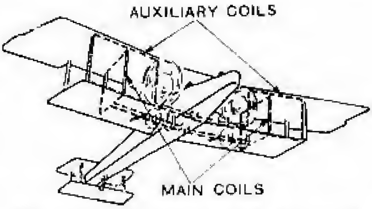

Fig. 393.—Robinson D.F. Adapted to Wing Coil System.

An Early R.A.F. Homing System. In a modification of the Robinson system by the Royal Air Force, the switching from one connection of the coils to the other was performed automatically and, at the same time, the 90° ambiguity was eliminated. Instead of two switch positions, there are now three, and the circuit connections are as shown in Fig. 394 together with the resultant polar diagrams.

The switch is in the form of a radial commutator, on the dial of which there are three sectors which correspond with the three types of coil connection, and which are coloured White, Red and Green. Consider, firstly, the circuit when the switch is on the Red sector. Here the wing coil and the fore and aft coil are connected in series as shown, and the resultant diagram takes the form shown in Fig. 394 (*a*), namely, that of a wing coil which has been swung a small amount over to port. If, therefore, the aeroplane be flying directly towards a beacon transmitter, the strength of signal received with this connection will be proportional to O R, Fig. 394 (*a*).

With the switch in the Green sector, the auxiliary coil is reversed and the resultant diagram becomes that of Fig. 394 (*b*), which is seen to be equivalent to swinging the machine over to starboard. The reception from a station ahead is now proportional to O G, and by switching from one connection to the other the two signals can be matched.

To ensure that it is the signals proportional to O R and O G which have been matched, and not those proportional to O R′ and O G′, which would give a 90° error, the third sector of the switch connects only the wing coil in circuit, together with a balancing inductance replacing the fore and aft coil. In this case, the polar diagram is as in Fig. 394 (*c*), and clearly there should be no received signal. If a strong signal be received, then the machine has the transmitting station on the beam and not ahead.

In practice, the switch or commutator was driven at a speed of roughly one revolution per second by means of an air screw, though the speed could be varied to suit the circumstances. The pilot thus heard in his telephones two signals of equal strength with a silent period between them corresponding to the wing coil reception. When the signals were very strong, the rotary switch could be stopped on the White sector and the actual homing done on the wing coil alone.

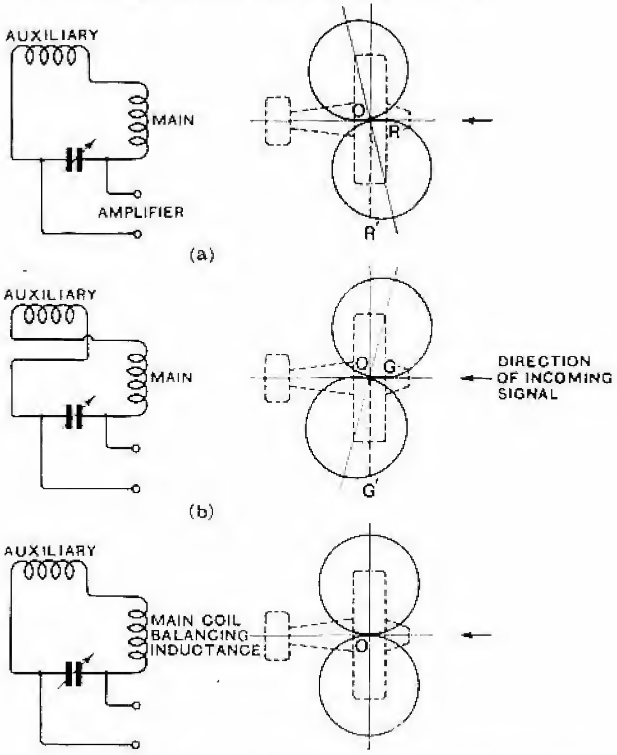

Fig. 394.—Early Adaptation of Robinson System to Equi-Signal Homing.

The Switched Cardioid. A somewhat later method of equi-signal switching, which employs a cardioid or similar unilateral diagram, is now widely used for homing. A fixed transverse loop is used to give a cosine diagram of reception as shown in Fig. 395, and an auxiliary aerial is switched into circuit, its e.m.f. being reversed in direction at intervals either manually or by an electrically-driven switch or by a method of switching employing a valve circuit. If the amplitude and phase of this open aerial e.m.f. be correctly adjusted, the result will be cardioid reception as illustrated, the minimum pointing alternately to the port and starboard sides. This is therefore a conventional equi-signal device, the signal amplitude in the direction OX being Ox on each cardioid, whilst in a direction OP, the signal strengths are Op_1 and Op_2.

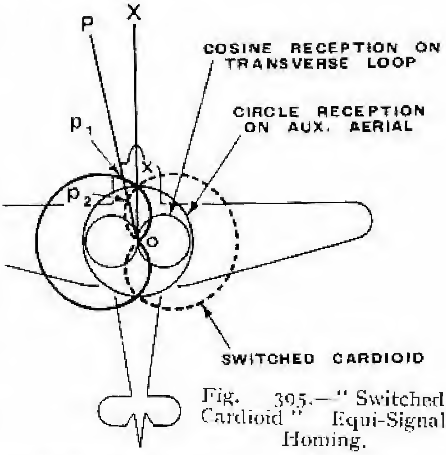
P
X
COSINE RECEPTION ON TRANSVERSE LOOP
CIRCLE RECEPTION ON AUX. AERIAL
p_1
p_2
x
O
SWITCHED CARDIOID

Fig. 395.—" Switched Cardioid " Equi-Signal Homing.

Although referred to in this chapter and elsewhere as switched "cardioids," the diagram is often not a true cardioid in shape, but unilateral, as this is easy to produce and gives very good signal contrast when switched.

Such a system may, of course, have either audible interlocked A/N signals or dot-dash signals incorporated, both of which have been described in the previous chapter, or visual indication may be used. An application of this system appears in several of the commercial designs of aircraft homing apparatus included at the end of this chapter.

Aural Homing with Mechanically Switched Cardioids. A circuit arrangement that is used, with small modifications, in several designs of aural equi-signal homing devices is shown in Fig. 396.

L_1 is the coupling coil in series with the loop, the mid point of either or both of which may be earthed. L_2 is a tightly-coupled secondary winding in the tuned grid circuit of the first H.F. valve of the receiver and amplifier.

L_3 is a tertiary winding connected, through the contacts of a rotary switch S_1, to the auxiliary or trailing aerial in the circuit of which is a phasing resistance R. It will be seen that this switch is arranged to connect the auxiliary aerial alternately to the top or bottom of the coil L_3, and the combination produces switched cardioids.

The contacts of the switch may be shaped to produce the A/N or Dot-Dash interlocked signals according to requirements.

HOMING WITH VISUAL INDICATION

The Radio Compass. In order that a pilot may listen to his engines, or carry on W/T or R/T communication, it is now common practice to equip homing devices with a centre zero meter for the purpose of giving visual indication of the homing course. This combination is given the specific title of "Radio Compass" in the U.S.A., as distinct from the Direction Finder that has aural indication only. A Radio Compass may have a rotating loop.

Visual Indicator Circuit Using Mechanically-Switched Cardioids. Fig. 397 shows a simplified diagram of a circuit using mechanical switching in order to operate a visual indicator, and may be compared with Fig. 396. The switch S_1 now has make and break periods of equal duration, and a second exactly similar switch S_2 is mounted to rotate synchronously with S_1. A portion of the low-frequency output is still diverted to telephone receivers, but the main output is now taken through a centre zero micro-ammeter, double or single rectifiers of the Westector type, and the contacts of S_2 in the way illustrated.

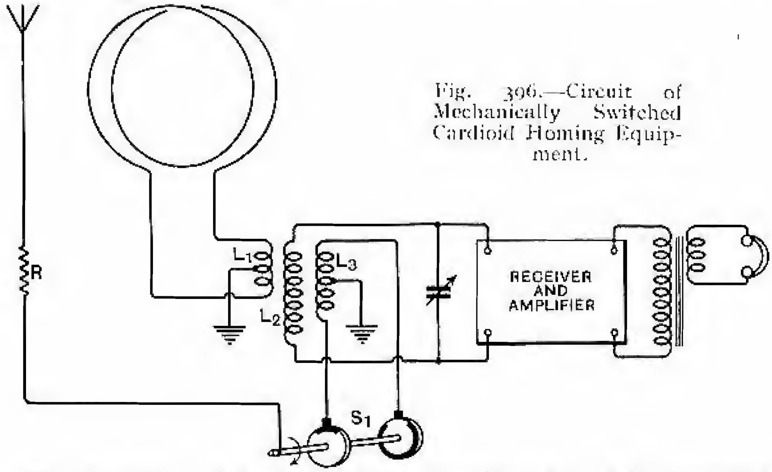

Fig. 396.—Circuit of Mechanically Switched Cardioid Homing Equipment.

The function of S_2 is to reverse the direction of the rectified output current through the centre zero instrument, in synchronism with the reversal of the cardioid reception, so that for actual equi-signal reception, when the plane of the loop is exactly at right angles to the direction of the transmitter, the pulses of current through the meter are equal in duration and amplitude, but alternating in direction. The speed of reversal is usually about ten times per second and the movement of the meter is damped sufficiently to cause it to remain stationary for equi-signal indication.

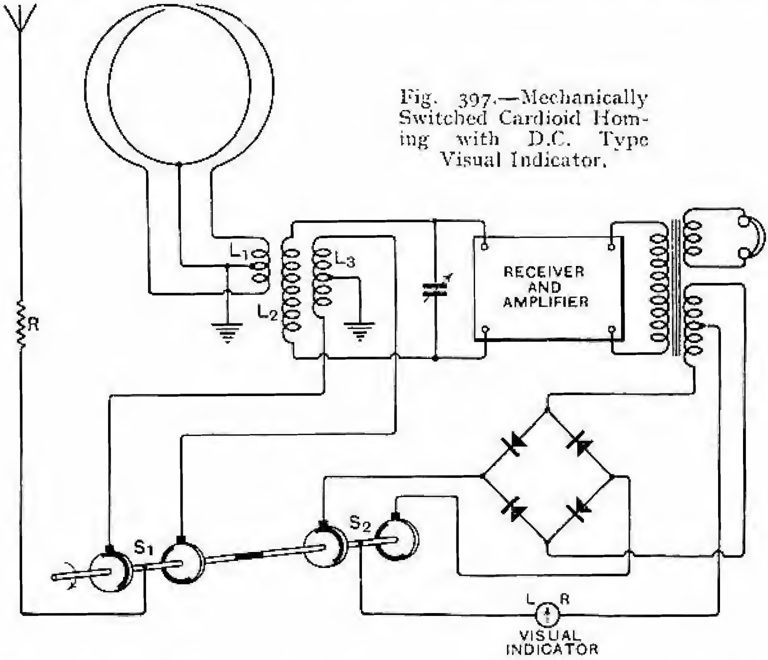

Fig. 397.—Mechanically Switched Cardioid Homing with D.C. Type Visual Indicator.

With a movement of the loop away from the equi-signal position, the signal inputs, which now represent unequal ordinates of the two cardioids (see Fig. 395), result in varying output from the receiver. Since S_1 and S_2 are synchronized, there are now unbalanced rectified D.C. pulses applied to the indicator meter, with an appropriate deflection to one side or the other according to the direction of rotation of the loop.

This mechanical method of switching cardioid diagrams, with synchronous switching of an indicator circuit, appears to have originated with M. Dieckmann in Germany and was later extended by R. Hell to the valve-switching method described below (2911). The principle of mechanical switching is used in the apparatus of the Telefunken Company of Berlin and also in that of the Marconi Company, both of which are described later.

Valve-Switched Cardioids with Dynamometer Type Visual Indicator. This method of aerial switching is illustrated in Fig. 398. The anodes of two valves V_1 and V_2 are strapped together and connected to a winding of the R.F. transformer T_2, another coil of which supplies an auxiliary aerial e.m.f., the phases of these currents being adjusted, when either valve is conducting, to produce a cardioid diagram which is applied to the radio frequency amplifier.

The grids of V_1 and V_2 are normally biassed so that neither has any anode current flowing, but the transformer T_1 applies a low-frequency alternating e.m.f. (say about 100 cycles) to the grids, so that the valves become conducting in alternate half cycles.

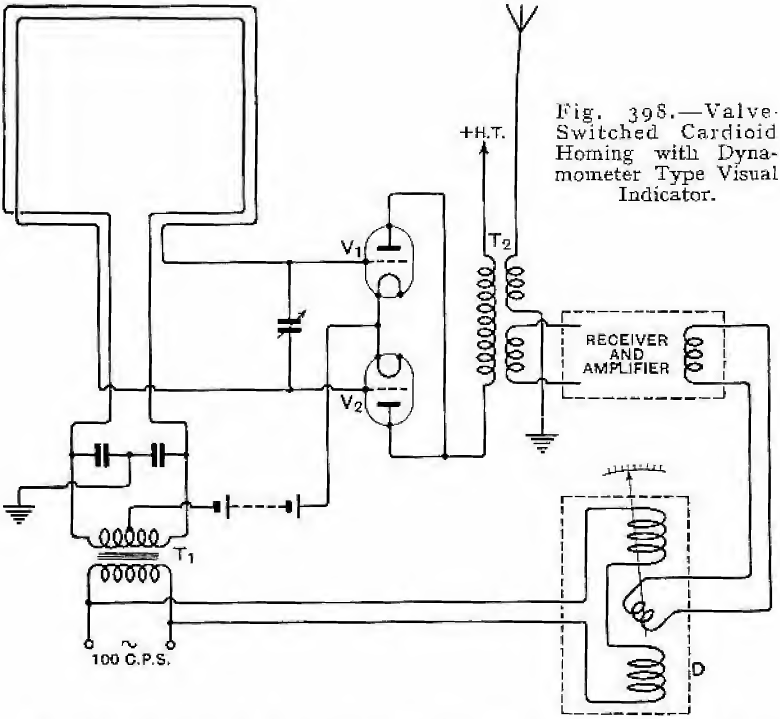

Fig. 398.—Valve-Switched Cardioid Homing with Dynamometer Type Visual Indicator.

Bearing in mind that the signal voltage across the loop changes phase as the loop is rotated through the cosine minimum direction (page 65), suppose it now to be turned slightly, say clockwise from the minimum position, and that the signal applied to V_1 results in an e.m.f. at T_2, that is additive to the auxiliary aerial e.m.f. The loop signal applied to V_2 will then subtract from the auxiliary aerial e.m.f. Therefore, when the valves V_1 and V_2 are alternately cut on and off, the auxiliary aerial signal will be alternately augmented and diminished by the loop signal and will, in effect, be modulated at a frequency of 100 cycles per second.

If, now, the loop be rotated anti-clockwise from the cosine minimum position, the phase of the signals to V_1 and V_2 will be reversed. Additions of signal at T_2 will become subtractions, and vice versa. The result is a similar 100-cycle modulation of the auxiliary aerial signal, but the phase of the modulation is reversed.

The modulated signal is amplified in the radio receiver and rectified in the usual manner, the output of the audio frequency amplifier being the 100-cycle modulation, with phase varying according to the position of the loop relative to the direction of the incoming signal.

There are several ways in which the output of the L.F. amplifier and the original modulating frequency can be combined to produce visual indication of the radio frequency signal intensity and phase. Hell used a dynamometer, as shown at D in Fig. 398, the output signal being applied to the moving coil and the original modulation to the fixed coil. With zero output, the moving coil is restored by spring control to a centre zero reading, but is rotated in one direction or the other by an output, the direction depending upon the phase relation of the output to that of the original source.

Alternative methods of obtaining similar results are given later in this chapter when describing the equipment of the R.C.A. Mfg. Company, Inc., Lear Developments, Inc., and Standard Telephones and Cables, Ltd., which make use of modified forms of the above principle in their aircraft homing apparatus.

Homing on a W/T Transmitter. Equi-signal switching, with a visual indicator, has the disadvantage that it cannot conveniently be used on a W/T transmitter. The signal is, in this case, already broken up by morse transmission, and unless the speed of transmission is fairly high, it is liable to cause erratic swinging of the pointer of the meter, which will mask the effect of the loop movements. In any case, even high-speed commercial morse transmitters revert to slow sending for passing service instructions and for other reasons.

A manual change-over switch of sturdy design is therefore often an advantage for use in such cases, reserving the automatic switching for use on beacons, the carrier of telephony transmitters and high-speed morse. Such a switch will be seen in the Marconi Company apparatus in Fig. 409.

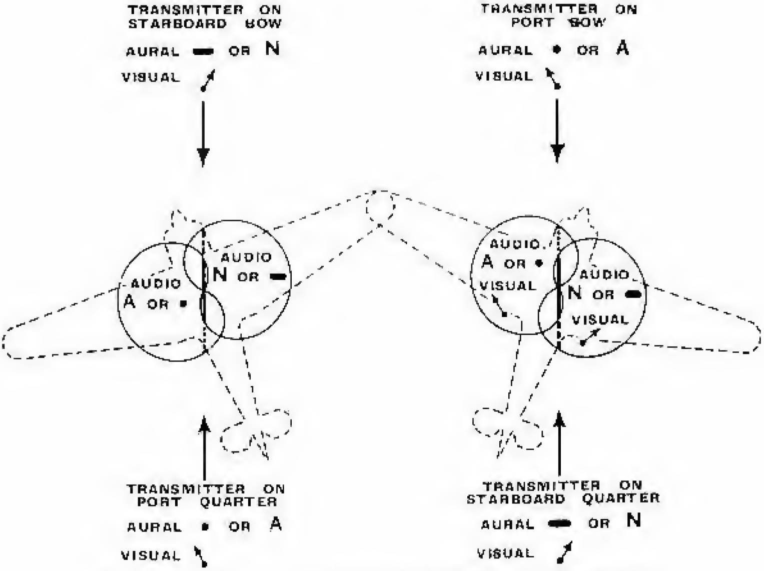

Fig. 399.—Ahead and Astern Indications when Homing.

VISUAL INDICATOR MOVEMENTS WHEN HOMING

Sense Indication. No sense indication of the conventional kind is normally incorporated in homing apparatus, since it is at once apparent from the behaviour of both audio and visual indication whether the transmitter is ahead or astern. An aeroplane fitted with homing gear is shown in Fig. 399 in the two off-course conditions, namely, to port and starboard. When off-course so that the transmitter is on the starboard bow (ahead on right), assume that the apparatus is arranged to give the N or — signal on audio working, whilst the visual indicator pointer moves to the right as shown. The reverse occurs, namely, an A or · signal and a left pointer movement when the aircraft steers so that the beacon is on the port bow (ahead on left).

With the transmitter astern, an examination of the switched cardioid diagrams shows that the indications are reversed.

It follows from this, therefore, that if off-course with an

A or · signal, and starboard rudder (right turn) *decreases* the A or ·, the transmitter is *astern*, and so on.

In the case of visual indication, the first movement of the indicator is *away* from the rudder movement for a transmitter ahead. If, however, the movement of the indicator becomes greater in the *same* direction as the rudder or steering movement, the transmitter is *astern*.

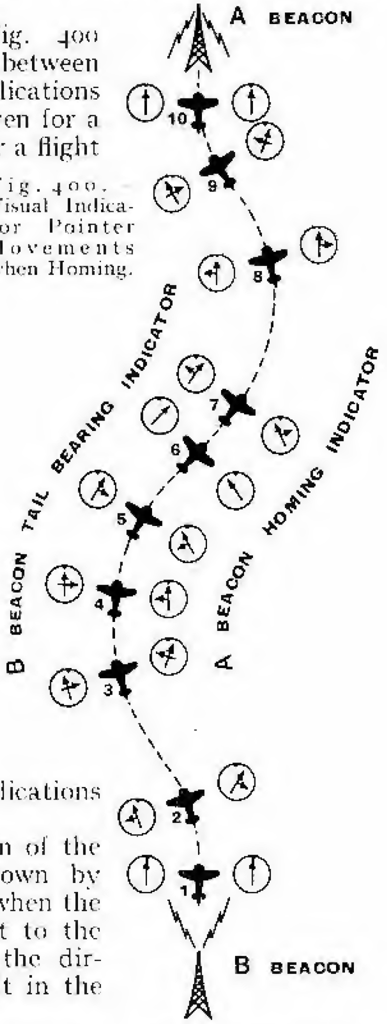

Fig. 400. Visual Indicator Pointer Movements when Homing.

Pointer Movements. Fig. 400 shows the track of an aeroplane between beacons B and A, the visual indications by pointer movement being given for a homing flight to A as well as for a flight from B using "tail bearings." From these it will be seen that, for the former case, the pointer is central whenever the aircraft points to the beacon, as in positions (1), (4), (8) and (10); it is right when the beacon is to the right ahead, and left when the beacon is to the left ahead. Further, when the aircraft is making a right turn as at (3), (4), (5) and (9) the pointer is always moving left, regardless of its position on the scale, and it moves right for a left turn as at (2), (7) and (8).

In the reciprocal homing flight from B, the pointer is again central when the aircraft is flying directly away from B, but all the remaining indications are exactly reversed.

Note that the centre position of the pointer is taken to be as shown by the scale mark, that is to say when the pointer is vertical with respect to the page and not with respect to the directions of flight of the aircraft in the individual positions shown.

Reversal of Pointer Movements. It is necessary to note carefully the scheme of pointer movements adopted in the case of each commercial homing system, as the indicator is sometimes connected to give deflection right for a right turn with the beacon ahead. This reverses all the above-mentioned movements but the principle involved remains identical.

In some cases a reversing switch is fitted, the two positions being labelled TRANSMITTER AHEAD and TRANSMITTER ASTERN, and by putting this switch in the appropriate position, the indicator movements for left or right turn will be the same for ahead or astern positions of the transmitter, the relative position of which will be shown by the switch position.

Comparison of Equi-Signal Beacon Course and Equi-Signal Homing. Fig. 400 shows also the fundamental difference between the equi-signal beacon transmitter course and the homing principle. With an equi-signal course from A, along the line AB, the aircraft in positions (2) to (5) would get A or · aural or, say, left pointer indication, whilst (7) to (9) would be the opposite, on the assumption of a receiving aerial of such a type and so rigged as to be free of course error. (Page 516.) Positions (1), (6) and (10) would all be " on-course." The lack of indication of the orientation of the aeroplane in the equi-signal beacon system is, of course, due to the directive properties being vested in the transmitter, whilst the aircraft has a non-directive aerial system.

It must be remembered that homing is here being studied purely as a wireless problem. In the normal homing flight, the instrument equipment in the aircraft and the W/T apparatus would be supplementary to one another—the directional gyro, for instance, supplying the necessary information regarding orientation.

THE AIRCRAFT DIRECTION FINDER

An actual rotating loop D.F. installed in the aircraft is the most flexible method of using the directive properties of aerials as an aid to navigation, and it has most of the advantages set out in connection with the similar ship installation. In England the method is only now beginning to become popular, and up to the year 1938 few British aircraft, in civil use, have been fitted with properly calibrated rotating loop equipment.

In German and Swiss aircraft, the D.F. installation in the aeroplane is used to a somewhat greater extent, whilst homing equipment has been in fairly extensive use in England and elsewhere in Europe for some years.

The reason for the comparatively small use that has been made of the aircraft D.F. in Europe is that on the main civil flying routes in most European countries, ground D.F. stations are available, so that the urgency for facilities in the aircraft has not arisen. In the U.S.A., conditions are entirely different. Ground D.F. stations are rare, and aircraft is navigated during bad visibility by an extensive beacon system which is also available for homing flights and D.F. from the air. As a result, the rotating loop developed more rapidly in that country.

Examples of commercial installations will be found at the end of the chapter, preceded by some notes on calibration.

Types of Aircraft Rotating Loop. Rotating loops are almost always fitted externally and usually above the fuselage. In some cases they are retractable. The chief factors governing the design of a loop are as follows :—

(*a*) Ample effective height over the tuning range, which may necessitate the switching in and out of sections of the loop winding, as in the R.C.A. Mfg. Co. loop of Fig. 419 and 420.

(*b*) Low aerodynamic drag at high air speeds. It may be noted that a 20 lb. drag at a speed of 300 m.p.h. absorbs 16 horse power.

(*c*) Freedom from ill effects due to ice formation. An 18-inch diameter rotating loop has been known to ice up until the diameter of the hole through the ice ring was only 2 to 3 inches (3604). Certain types of ice affect the reception of signals by the loop, the drag is increased in any case, and rotation may be hindered or altogether prevented.

(*d*) Freedom from the effects of static caused by electrically charged particles of rain, sleet, sand or dust.

(*e*) Small weight combined with strength to withstand very high air speeds (a function of (*b*) above).

The Marconi Company 13-inch diameter metal-screened loop of Fig. 408 is a conventional type and, as fitted to the Imperial Airways flying boats, is made retractable, thus avoiding the ill effects of drag and ice formation except during the time it is in use for taking bearings. In designing retractable loops it is necessary to take into account the possibility of the loop being used for prolonged periods, or alternatively of very rapid ice formation, and the slot through which the loop is withdrawn must be made of ample width and the withdrawal fittings of such form that they will not fail due to this cause.

The Streamlined Loop Housing. Present tendencies in loop design are towards very small dimensions and a streamlined housing of the form seen in Fig. 419. This shield is usually made of bakelite or similar material and protects the whole of the moving parts from the elements, thus avoiding most of the ill effects of ice formation, eliminating rain and sand static, and greatly reducing aerodynamic drag. In addition to these advantages, the loop, being very small and not subjected to air movements, no longer requires robust control apparatus, as can be seen from the mechanism of Fig. 420. Furthermore it can be installed in a position of minimum error and this point is referred to again on page 523.

The Airship D.F. The amount of data on the airship D.F. installation is necessarily limited, but Fig. 401 shows two rotating loops below the hull of a German airship, the twin Q.E. correcting loops on either side having already been described on page 438.

The purpose of the additional D.F. is for landing operations during bad visibility, the method adopted being mentioned on page 654.

The D.F. receiver is equipped for pulse reception for the elimination of polarization errors (page 223) as well as for normal medium and long wave D.F., and a paragraph on page 526 refers to the errors to which the airship installation is subject.

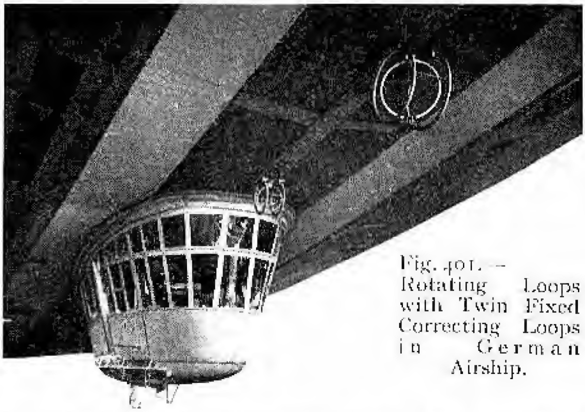

Fig. 401.—Rotating Loops with Twin Fixed Correcting Loops in German Airship.

THE BELLINI-TOSI SYSTEM IN AIRCRAFT

Bellini-Tosi aerials have been fitted in a number of aircraft in this country, but chiefly for special purposes, and none of them recently. One of these was the V-1500 type Handley-Page aeroplane that was intended to be used for the first trans-Atlantic flight, and was making final preparations in Nova Scotia in 1919 when forestalled by the Vickers' " Vimy " piloted by Alcock and Brown. The Handley-Page had a wing spread of about 120 feet and a fuselage length of 80 feet, and large wing loops were rigged without difficulty, whilst special vertical spars fore and aft supported the other loop. The D.F. results were fair, the apparatus being designed for working on wave lengths of several thousand metres, these being the only wave lengths on which transmitters would be heard over the required range in those days. The ignition screening was somewhat crude by present-day standards and noise from this source was extremely troublesome.

In 1925 a B-T installation was fitted in the Dornier Wal all-metal seaplane " Ne Plus Ultra," which was flown from Spain to the Argentine, and a diagram of the aerial loops is shown in Fig. 402. Owing to the engines being in the centre line, it was impossible to rig the fore and aft loop there, and a two-turn loop was used, the turns being supported on special struts which kept the loops well away from the engines and metal-work, and at the same time retained the symmetry. The two turns were connected in series and had a total area turn product of 250 square feet. The same struts also supported part of the wing loop.

This installation was successful and was instrumental in directing ships to the spot where the craft was forced down at sea on a subsequent flight.

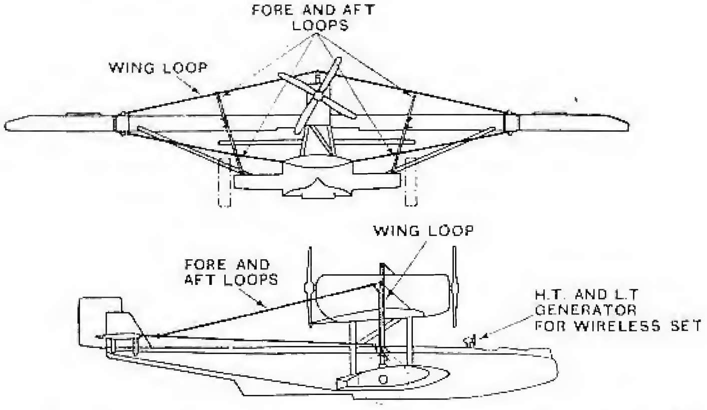

Fig. 402.—Arrangement of B-T Loops in the Dornier-Wal All-Metal Seaplane " Ne Plus Ultra " (Electrician).

The improvement of the rotating loop D.F., however, has caused the B-T system to be neglected of late years in its application to aircraft, though there is some possibility of its revival, since it permits the D.F. aerial system to be placed in the most efficient electrical site in the aircraft, without the necessity for lengthy mechanical remote control equipment.

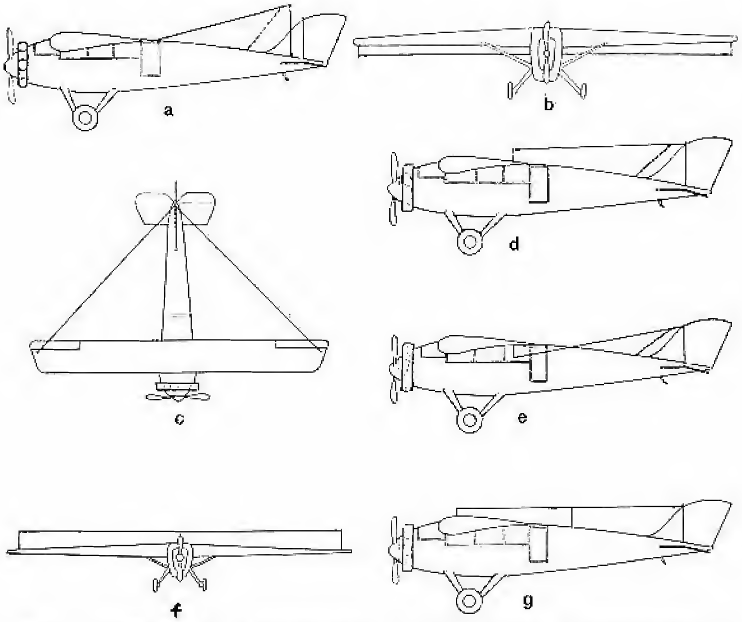

Fig. 403.—Forms of Aerial Tested by U.S. Bureau of Standards for Radio Range Beacon Reception (Bureau of Standards Journal of Research).

AERIALS FOR COMMUNICATION, SENSE DETERMINATION AND MEDIUM WAVE EQUI-SIGNAL BEACON RECEPTION

It is usually possible to obtain a cardioid, or at least a unilateral diagram of reception, using the aircraft communication aerial, but if navigation by means of equi-signal beacons is contemplated, care must be taken in the choice of the open aerial, and the communication aerial is often unsuitable. The errors liable to occur are not only in course indication, but also in the localization of the aircraft by the strength of received signal when flying over the beacon transmitter.

The vertical pole aerial, if rigged to a height of five or six feet, gives the best results with respect to accuracy on the course and sharp discrimination when flying over the beacon, together with adequate signal strength. The pole aerial has the disadvantage of projecting to an undesirable height above the aircraft, where it is subject to ice formation and also to the effects of vibration. In Fig. 403 are shown some of the forms of aerial that have been tested by the U.S. Bureau of Standards for use in its stead, the tests being described in (3107), which also includes a mathematical analysis of the subject with which the experimental results are found to be in close agreement.

Course Error. This error, in connection with equi-signal courses, is the one produced by the reception, on a sloping aerial, of signals from a loop transmitter. It corresponds exactly to the " aeroplane effect " mentioned on page 192 in the case of the ground D.F. station.

The tests were carried out at a height of 3,000 feet and at 3 miles radius from the beacon, flying broadside to the direction of the beacon in the case of the course error observations.

The pole aerial error was, of course, nil, as it has no sloping portion that can receive horizontally polarized electric force, and if the position for it be carefully selected, it should be almost free from this trouble. However, just as the vertical limbs of the Adcock aerial in Fig. 203 were influenced by the radiation from the horizontal screen, so the vertical aircraft aerial is coupled to the metal framing or skin of the machine. Both fuselage and the wings may be acting as horizontal aerials for any horizontally polarized component of the radiation from the beacon and there is thus a grave risk of the vertical aerial behaving as though it had a horizontal member attached. This effect is much more marked on ultra-short waves than on medium waves and becomes a serious problem in the Approach and Landing Systems described in Chapter 15.

By putting the aerial on the longitudinal centre line of the aircraft, a balance can be obtained for incident waves fore and aft, and if the aerial be moved along this centre line, a point may possibly be found that gives a balance for signals on the beam, but some residual aeroplane effect is likely to exist on ultra-short wave lengths. Compare the parallel problem of finding the best position for the D.F. loop, as mentioned on page 523.

With the inclined aerial of Fig. 403 (*a*), and also with the trailing aerial and the inclined V type of Fig. 403 (*e*), errors up to 20° were observed, but both the transverse and longitudinal T aerials (*f*) and (*g*) gave satisfactory results. As would be expected, the sloping aerials showed no error when flying towards or away from the beacon.

Localizing Effect. This term is used in the above tests with reference to the ability to determine accurately the position of the aircraft by the drop in signal strength as it flies over the beacon transmitter. The pole aerial gave particularly good results in this connection, signals falling to zero within a narrow vertical cone above the beacon. The inclined aerials gave poor results, their receiving diagram being very unsymmetrical with respect to a vertical line dropped from the aircraft to the ground. Both the T aerials again gave satisfactory results.

The evidence of the tests pointed to the longitudinal T aerial being the most satisfactory, as it suffered less from ice formation than the transverse T. This aerial can be rigged as low as 10 to 18 inches above the fuselage, as compared with 5 to 6 feet in the case of the pole aerial.

INSTALLATION AND RIGGING IN AIRCRAFT

Marine D.F. installation work has been seen to be subject to far more regulations than similar work on shore, and the standard of workmanship must conform in every way to the standard ship practice, so that if a D.F. is to be installed in a ship that is already in commission, expert advice is essential before cutting holes in bulkhead or deck.

The installation of wireless gear in aircraft is still more specialized, and the necessary alterations to the structure and the rigging of aerials are almost invariably carried out by aircraft construction companies under close inspection. Thus, should a wireless manufacturing company be approached by a civil aircraft owner with a view to the fitting of a homing device, arrangements will be made at the same time as to the aircraft company who will supervise the necessary work.

The necessity for this is mainly due to the factors of safety in aircraft construction being so much lower than in ship or shore structures that it would be most unwise to allow any but trained aircraftmen and riggers to make alterations of any kind whatever. The aircraft companies have their own inspectors who investigate all the work done, including the runs of cabling, bonding, and the installation work that is being done by the wireless manufacturers. In the case of installations in new types of aircraft or in aircraft of a type not previously fitted with wireless apparatus, the work must be carried out in conjunction with an aircraft company of approved standing or under the direct supervision of the Airworthiness Department of the Air Ministry. In addition, all subsequent installations must receive the approval of the Aeronautical Inspection Department (A.I.D.), and there is no question of these precautions being other than fully justified.

Whenever possible, however, provision is made for the wireless apparatus when the aircraft is being built, in which case the fuselage type homing coil may be incorporated in the construction, fittings arranged to take the wind-driven W/T generator, the rotating loop mountings put in a convenient position, and provision made for safe cable runs together with much other detail work.

Electrical Bonding. The electrical bonding of the metal work in an aeroplane is necessary for the prevention of fire when a W/T or R/T transmitter is being used, and is carried out in such a way as to ensure that the copper braid coverings of the complex wiring system of the aircraft are connected to the " earth " trunk at many places and the possibility of sparking reduced to a minimum. This serves the double purpose of also avoiding lengths of screened covering either resonating at some harmonic of the received wave and affecting the calibration of the D.F., or of making intermittent rubbing contact with other conductors and producing both errors and receiver noise.

There is, however, the possibility that the large closed loops, which are produced in the bonding process, will greatly affect the reception of either a fuselage or a rotating loop. Due allowance can be made for this when calibrating, but it must be remembered that the removal or addition of a single bonding connection may necessitate a complete re-calibration in certain cases.

Precautions in Fitting Apparatus. In small passenger-carrying aircraft of the cabin type, there is often some difficulty in finding available space for the apparatus, which is at the same time out of reach of passengers. The pilot's cockpit will be arranged for dual control, and it is possible that there is only room there for remote control gear, the transmitter and D.F. receiver and amplifier being in the passengers' cabin. In this case, not only is it important that no H.T. or L.T. terminals are exposed so as to be a danger from electric shock or fire, but the apparatus should also be protected by a guard of some kind, if only a hand rail. If apparatus be mounted at the rear of the cabin, near to the door or gangway, a passenger stumbling on entry or due to a movement of the aircraft, may seize a bunch of wiring to steady himself and possibly put the gear out of action due to a minor breakage.

Effects of Vibration. The constant vibration during flight and also the landing shocks have a destructive effect on all wireless apparatus and as much as possible of the equipment should be supported on shock absorbers. To prevent the internal connections of amplifiers and other instruments from coming adrift, the wires should always have pinched or screwed joints, in addition to being soldered. A loose connection or a loose electrode in a valve will produce a noise in the telephones which may be as serious as, and may even be mistaken for, ignition interference.

IGNITION CIRCUIT INTERFERENCE

Ignition interference in aircraft is not peculiar to D.F. work and the technique of the screening and bonding of the whole of the electrical system has been brought to a comparatively high standard for R/T communication.

When using a loop aerial, however, the trouble is exaggerated, for the aerial is now nearer to the source of the radiation than is the trailing aerial and, in addition to this, the loop aerial, due to its smaller effective height, requires a higher receiver gain.

As will be well known, the interference is due to highly damped waves radiated from the plug leads of the engines which, when the spark takes place, constitute short transmitting aerials. The lengths of the leads vary with the layout of the system, but radiate chiefly ultra-short waves so that reception in this band, for equi-signal approach or landing, requires a far higher standard of shielding than does medium wave working. That this radiation may still be a serious source of trouble on longer waves may be gauged from the fact that bearings have been taken by a ship D.F. receiver, tuned to 300 m., on an aeroplane a mile distant and which was not fitted with a transmitter, the radiation from the ignition system being strong enough to provide fair signals at that range. Aircraft ignition interference is also a recognized source of trouble at commercial short-wave R/T receiving stations where large aerial arrays and high-gain receivers are in use.

The ignition leads are not the only radiating portion of the system however, for the cylinder wall forms the return path from the plug to the engine casing, and the interference due to this varies considerably with the type of cylinder construction. Steel and iron cylinders offer the greatest impedance to the high-frequency oscillatory currents and are the worst offenders, but an improvement is effected by fitting a copper bonding strip between the body of the plug and the engine framing. Less trouble is noticed in the case of non-ferrous cylinders having a steel liner ; a copper water jacket also acts as an efficient low impedance path.

High compression engines require a higher sparking potential and produce greater interference, and a gradual increase in the noise has been noted from an engine as the cylinders and piston heads became carbonised, with corresponding increase in compression.

In certain cases very little screening is required. Rotary engines have only very short lengths of ignition wiring which is kept close to the cylinder wall in every case, and the interference from such a system is not so troublesome as from a stationary engine, which frequently has duplicate ignition controlled from the cockpit with great lengths of wiring.

Again, the metal cowling of the majority of stationary engines helps somewhat with screening on medium wave lengths provided that it is made to surround the engine completely (3010).

Suppression of Ignition Interference. Rejector circuits of various kinds have been tried in the plug leads, and also choke or resistance suppressor units, but a more satisfactory solution was found to be the complete screening of the whole of the ignition system, including the magnetos and distributors, any controls leading to the cockpit, the plug leads and the plugs themselves. An account is given by F. H. Drake (2915) in which the permissible sensitivity of an aircraft receiver—which is a function of the noise level—is plotted in graph form for various degrees of screening. The engine was a Wright " Whirlwind " Motor (American) and the total range of noise reduction was roughly 60 db. (to 1/1,000th voltage). These figures have been improved in more recent years but they confirm the importance of not leaving any ignition cable exposed, the difference between conditions with one inch of cable exposed at the plug and those with completely screened cable and screened plug being 32 db. (1/40th voltage).

The adoption of screening for magnetos, distributors, cables and plugs immediately led to ignition troubles, tests with and without screened cables showing, for instance, a reduction of 30% in the available voltage at the plugs, due mainly to the capacity between the conductor and the screening. In bad weather, rain found its way into the early types of screened plugs and caused ignition failures and, as a result, the Air Ministry in this country did not approve anything more extensive than the shielding of the cable to within an inch or two of the plug, or occasionally the screening was extended to the plugs and a cap was fitted similar to No. 3 and 4 in Fig. 404. Still more rarely, the distributor was screened but hardly ever the magneto.

With special magnetos, having a 20% greater output than normal, and with a general improvement in screened plug design and in the construction of the remaining screens, a more satisfactory system was obtained which allowed of ultra-short wave reception being carried out in the aircraft.

A disadvantage, however, of any type of piecemeal ignition shielding is that it is usually necessary to employ metal braided

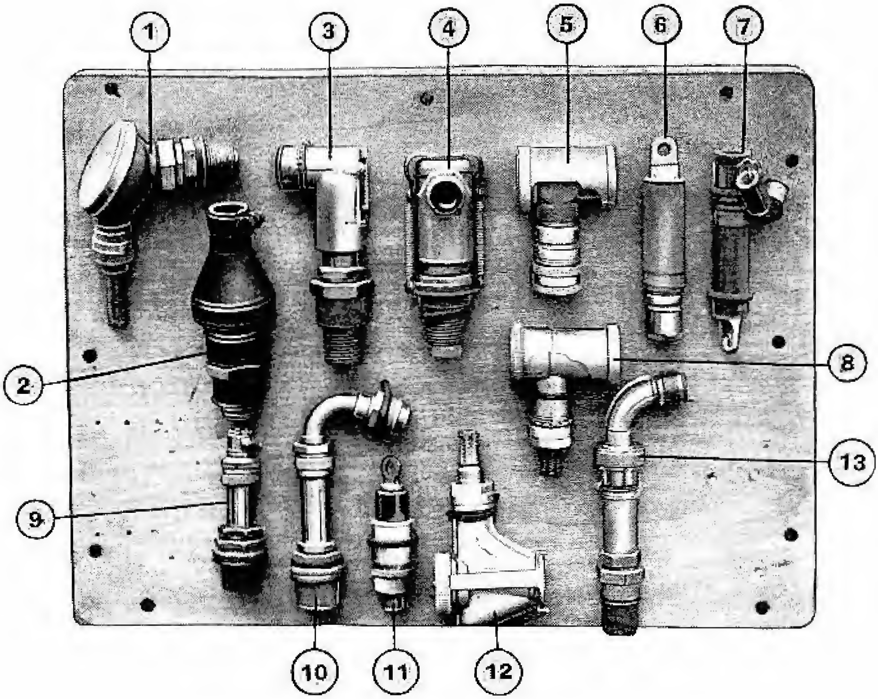

Fig. 404.—Types of Screened Plugs and Suppressors.
(Courtesy of Marconi's Wireless Telegraph Co. Ltd.)

1. Hurley Townsend Plug and Screen.
2. Marconi Plug Screen.
3. K.L.G. Plug and Screen.
4. Lodge Plug Screen.
5. Lodge Plug Screen.
6 and 7. Scintilla Choke Suppressor.
8. K.L.G. Plug Screen.
9. Hahn Screened Plug.
10. B.G. Screened Plug.
11. Italian Resistance Suppressor.
12. K.L.G. Plug Screen.
13. Lodge Screened Plug.

or woven screening for the ignition leads and this material is subject to deterioration with time and severe weather conditions.

Screened Sparking Plugs. There are two essentially different methods of construction of screened plugs, namely with separate wireless screen for attachment to the plug and the more modern type with the screen made integral with the body of the plug. Fig. 404 shows a series of plugs and other protective devices of varying dates.

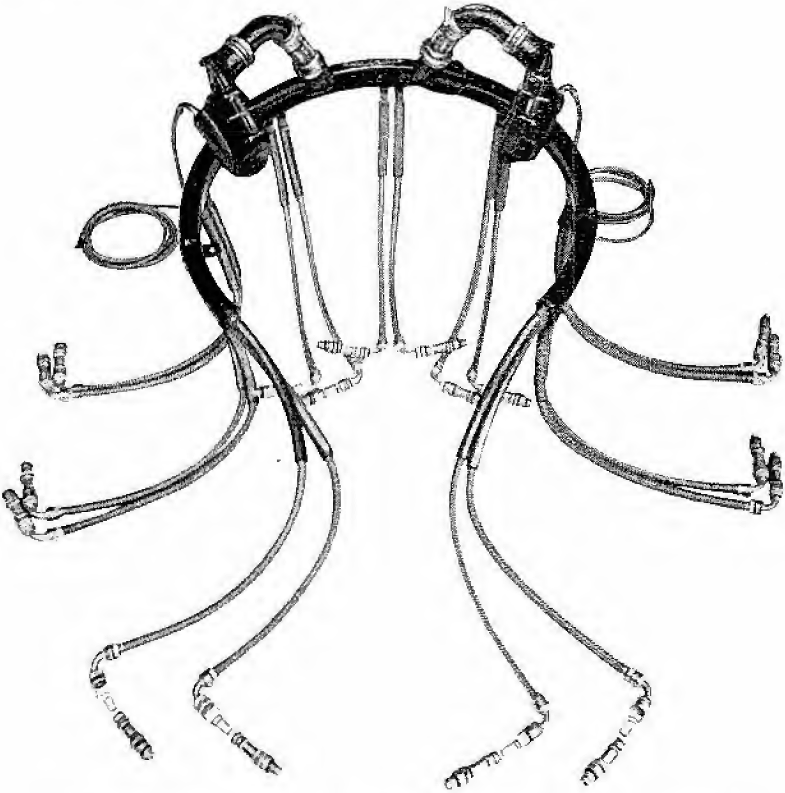

Fig. 405.—Marconi Ignition Screening Harness for Bristol "Pegasus" Radial Engine.

Ignition Screening Harness. In order to reduce the capacity of the screening of the cables, and to avoid the bulk and inconvenience of large numbers of separately screened leads, the whole wiring system of an engine may be built into a unit known as "screening harness." Fig. 405 shows such a harness as supplied by the Marconi Company for a Bristol "Pegasus" radial engine. The distributor screens are seen to be attached, and also screened plugs.

The reduction of interference with this method is appreciably greater than with the individual screening of leads, but still leaves some room for improvement.

American Progress in Ignition Noise Suppression. In the U.S.A., the problem of ignition noise has been tackled at its origin in the engine and in some engine designs, the plug and associated wiring are enclosed in chambers or channels which actually form a part of the cylinder. In the case of the Wright "Whirlwind," for instance, the pick-up is so low that even when receiving on the loop aerial and at heights of 5,000 feet or more, the noise level in the telephones increases very noticeably when flying over a town, due to the radiation from the industrial and domestic electrical apparatus.

CALIBRATION OF THE AIRCRAFT D.F.

When the installation, in addition to being used for homing, is to supply correct relative bearings, an error curve must be plotted in the same way as for a ship D.F. and the form of the curve may be quadrantal as in a ship, or octantal, depending on the location of the D.F. loop.

Aircraft Octantal Error. The reason for a variable type of error is illustrated in Fig. 406, where the upper diagram shows the fuselage of an aircraft, with a D.F. loop at some point X. From what has been said in Chapter 11 regarding the Q.E. curve of an uncorrected ship D.F., it will be clear that the error curve for such a structure and loop position will be as shown in the corresponding graph of Fig. 406 (*a*), the error being negative in the 0° to 90° quadrant.

Now consider the wings alone, as in Fig. 406 (*b*), where the D.F. loop is at some point Y but the scale of the D.F. is still assumed to read 0° for bearings ahead. The structure is again comparable to a ship, but with its hull at right angles to the previous one. Again a Q.E. results but, in this case, bearings will be crowded towards the 90°–270° line instead of the usual 0°–90° line, so that the error curve is moved laterally through 90° and errors are positive in the 0°–90° quadrant.

In the complete aeroplane as in Fig. 406 (*c*), the question of Q.E. correction can now be neatly handled by selecting some position such as, say, Z where experiment shows that the Q.E. of the fuselage and wings are as nearly opposed as possible, and in some cases a fair balance can be obtained. It can, however, be shown that a complete balance is unobtainable from the combination of the two Q.E. components, when due account is taken of their relative phases, and that there must be a residual octantal effect as in Fig. 506 (*c*). In practice, owing to the wing structure frequently being unsymmetrical about the longitudinal centre line, the wing Q.E. curve may take a form such as shown in Fig. 348 (*a*) and so render a balance more difficult, though fairly clean octantal curves are obtainable in some cases.

In very large aircraft, it may be necessary to locate the D.F. loop over the W/T office, near to the cockpit or control room, and the above method of balancing errors is then ruled out—a point much in favour of the B-T system or the small remotely controlled loop.

The covering of a large error by means of a correction chart is always undesirable, for reasons stated on page 362, and the importance of finding a solution of the aircraft error problem may be gauged from the fact that 30° is not abnormal for a Q.E. maximum. In such a case a residual octantal error of 10° or 12° would still exist after balancing and means for its elimination are at present the subject of investigation in various laboratories.

Air and Ground Tests. Calibration can, if necessary, be carried out on the ground, swinging the aircraft on an aerodrome compass bed or measuring the angle by means of a sextant, whilst observing the apparent bearings of distant transmitters on the required wave lengths.

With the loop below the fuselage, the compass bed calibration will generally be useless. When the loop is above the fuselage, the general shape of the ground error curve will be the same as if taken in the air but the extent of the corrections required may vary by several degrees and advantage should be taken of air tests if these can possibly be arranged. Careful note must be taken in this case of the condition of the trailing aerial when using the D.F. If this aerial be out during the test, it is preferable that it should be completely clear of the fuselage, being let out on a lanyard so as to be free of the fairlead and not merely disconnected inside the fuselage.

If a circuit is being used that employs a cardioid, either for sense determination or for a homing device, it is quite essential that air tests should be made. Unlike the ship or shore station there is no ground connection and the behaviour of open aerials may be greatly modified. Some difficulty may be found in obtaining a satisfactory diagram with a very small fin aerial, and it may also be noted that there is a sense reversal when the open aerial is rigged below instead of above the fuselage.

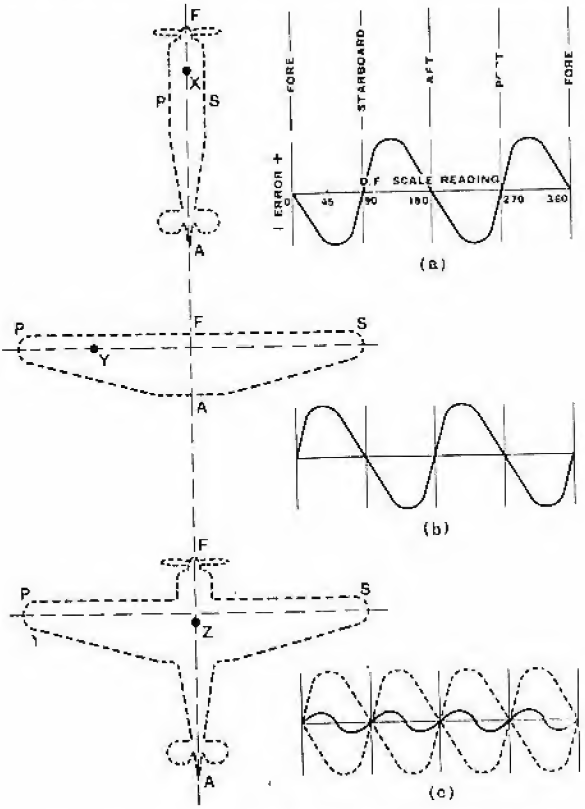

Fig. 406.—Aircraft Quadrantal and Octantal Errors.

Errors, indefinite cosine minima and distorted polar diagrams of reception that are variable in character may be due to bad bonding in some parts of the structure or cable runs, allowing a conductor to assume varying potentials and to re-radiate to the loop. It is practically impossible to arrive at a stable correction curve until such faults have been rectified (2905) (2515).

Error Curve of D.F. in Flying Boat. Fig. 407 shows the error curve of the Imperial Airways R.M.A. "Cambria," errors in the direction finder readings being plotted against correct relative bearings, that is to say, against bearings from the ship's head, which was held on a steady course read from the port magnetic compass.*

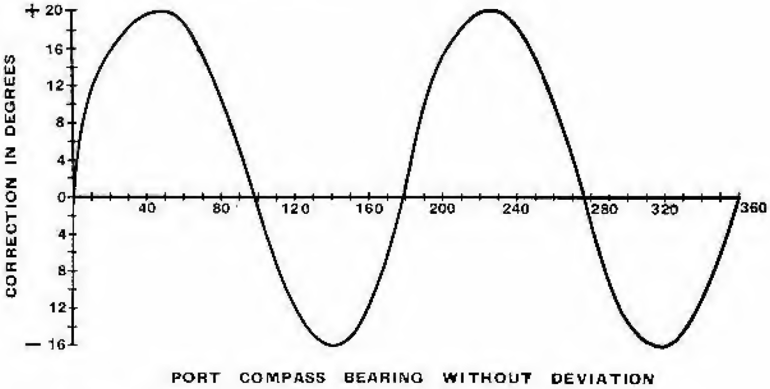

Fig. 407.—Correction Curve of Imperial Airways' R.M.A. " Cambria."

All the bearings for this calibration were taken on Droitwich 1,500 m. (200 kc.), the average height of the aircraft being 1,500 feet and the mean position being over the extreme easterly point of the Isle of Wight. The bearings were taken whilst the aircraft flew over the above point on a series of compass courses.

It will be noticed that there is a pointer error of 2° which, if corrected, would make the maximum and minimum Q.E. each equal to 18°. Apart from this the curve is a good example of aircraft Q.E. and fairly typical in shape for a loop position well forward of the wings. The position may be seen from Fig. 408, which shows a similar type of vessel.

Both trailing and fixed auxiliary aerials were isolated during the test.

ERRORS OF THE AIRSHIP D.F.

In the large rigid German airships, two forms of error occur that are inherent in the shape of the metal hull and envelope, the first being the familiar Q.E. and the second an effect that has been named **Dipole Error.**

The Q.E. in the case of these ships amounts to 20° and is reduced to a maximum of 0·5° by the compensating loop shown in Fig. 401.

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* From data kindly supplied by Messrs. Imperial Airways Ltd. and Messrs. Marconi's Wireless Telegraph Company Ltd.

The dipole error is variable and is a maximum on wave lengths of 500 to 600 m., coinciding with the natural wave length of the hull. The error occurs when the airship is not horizontal and when an e.m.f. is thus induced in the hull by vertically polarized waves and results in re-radiation to the D.F. loops. Until a means of compensating for this error is found, it is customary to maintain the airship horizontal when bearings are being taken (3608).

EXAMPLES OF AIRCRAFT D.F. AND HOMING EQUIPMENT

The chapter concludes with some examples of aircraft equipment, the remarks at the foot of page 447 with regard to the similar section on ship equipment, applying with equal force in this case.

Owing to the rapid development that is taking place in aircraft D.F. gear, it is perhaps still more important that the apparatus described should be taken only as illustrative of the period up to 1937, as some of the designs were in process of being superseded at the time that the information was supplied for the purposes of this chapter.

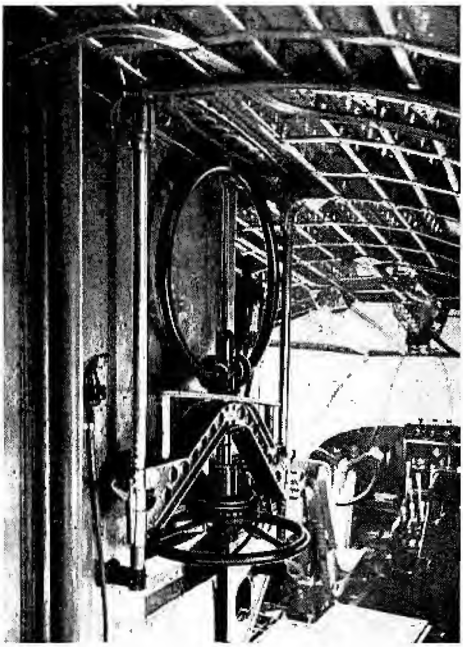


Fig. 408.—Marconi Retractable Loop as Fitted in Imperial Airways Empire Flying Boat.

MARCONI AIRCRAFT D.F. RECEIVER TYPE A.D. 5062 B.

This apparatus is designed for use either as a separate installation in small commercial or private aircraft or in combination with certain Marconi aircraft transmitters in which case it replaces the receiver used for normal communication work.

The receiver is used either with a fixed or rotatable screened frame aerial together with a fixed or trailing open aerial. A visual indicator can be added if required.

The whole equipment permits of (*a*) normal reception using the open aerial, (*b*) homing using the fixed frame in conjunction with the open aerial and (*c*) direction finding using the rotating loop.

Wave Range. The wave range covered is 600 to 1,550 m. (500 to 193 kc.) in two ranges of approximately 600 to 1,200 m. and 1,100 to 1,550 m.

H.T. and L.T. Supplies. The H.T. supply for the receiver is taken from a small anode converter working off the aircraft L.T. system, which also provides the L.T. supply. If used in an aircraft in which a transmitter is installed, a common supply is used.

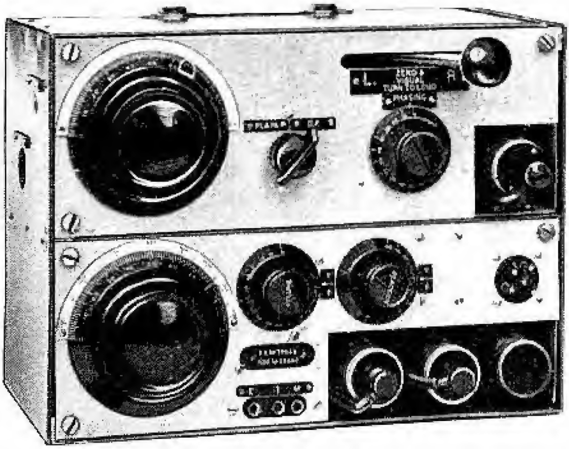


Fig. 409. — Marconi Type AD 5062 B Aircraft D.F. Receiver.

The Frame Aerial. The loop is similar in design to that shown in Fig. 408, but is not retractable. The interior wiring of the loop is a section of 18-core cable, insulated wires being arranged round the circumference of a hemp core and connected in series to give an 18-turn winding. The diameter is 13 inches.

Receiver. This is shown in Fig. 409, the top panel being the D.F. apparatus and the lower one the receiver and amplifier.

Circuit. A simplified circuit is given in Fig. 410, from which it is seen that the operation when using visual indication is identical with that described on page 505.

Rotary Switches. When the equipment of the aircraft includes a wind-driven generator for supply of H.T. for a transmitter, the rotary switches are driven by a D.C. motor from the 12-volt supply, but if an anode converter is used for the H.T. supply a drive is obtained from this source and the separate motor is not required. Fig. 411 shows the motor drive and aerial switches and also the visual indicator.

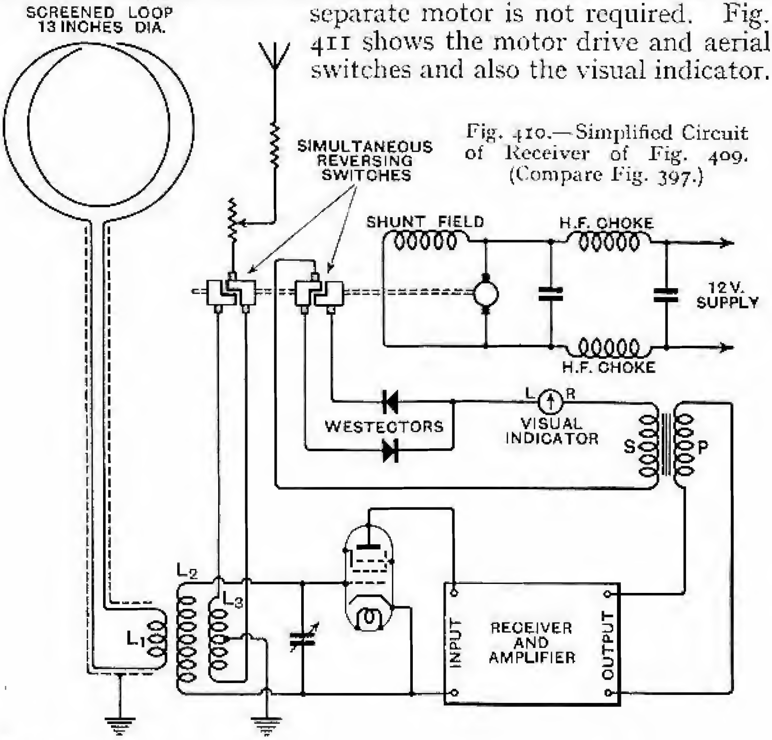


Fig. 410.—Simplified Circuit of Receiver of Fig. 409. (Compare Fig. 397.)

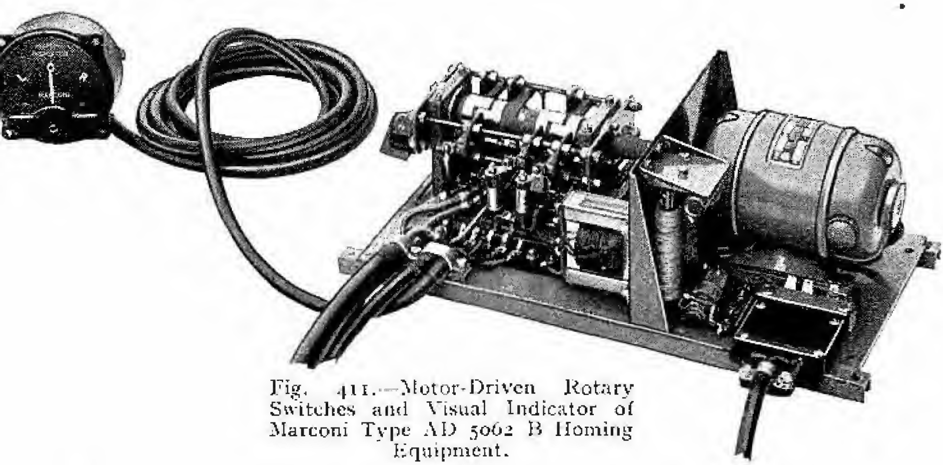


Fig. 411.—Motor-Driven Rotary Switches and Visual Indicator of Marconi Type AD 5062 B Homing Equipment.

Weight. The total weight of the installation with fixed frame, indicator, anode converter commutator switch, open aerial and necessary accessories is 36 lb. With rotating frame it is 44 lb.

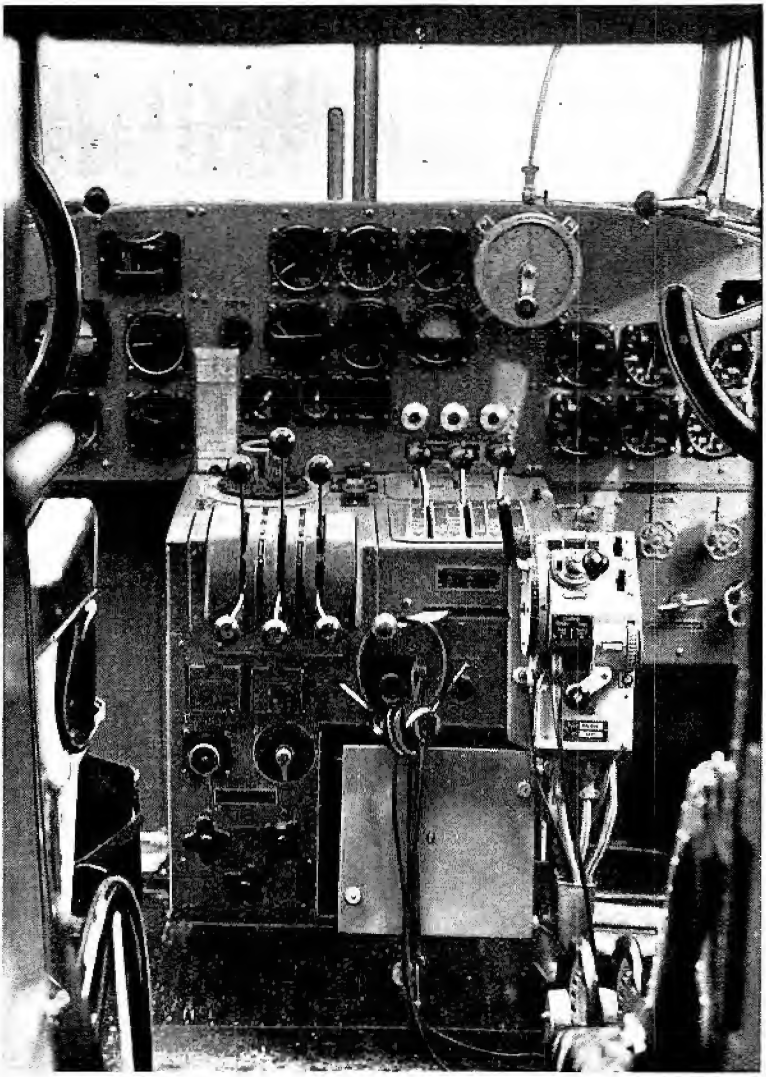


Fig. 412.—Telefunken Type P53N D.F. and Homing Apparatus Installed in Junker JU52 Aircraft.

THE TELEFUNKEN HOMING AND D.F. APPARATUS. TYPE P 53 N

This apparatus comprises a two-turn rotating loop and a receiver and amplifier, both of which are remotely controlled from the pilot's cockpit. In conjunction with an auxiliary non-directional aerial, 15 to 20 feet long, stretched between special struts above the fuselage, non-directional reception, homing with aural or visual indication and also D.F. can be carried out. A general view of the control apparatus mounted in a " Junker " JU 52 aeroplane is given in Fig. 412, whilst a more detailed view is shown in Fig. 413.

The wave range is 300 to 1,800 m. (1,000 to 167 kc.) using two bands, switching being done by the control No. 6 in Fig. 413. Low Tension supply for filaments is from the main battery of the aircraft and a 150-volt anode battery is used. The weight of the equipment, except for connecting cables and flexible drives, is 28 kg. (62 lb.).

Loop Aerial. The remotely controlled two-turn tubular steel loop is shown in Fig. 414. The turns have a diameter of 16½ inches and are strong enough to withstand air speeds of 280 m.p.h., at which speed the drag, with the loop set athwartships, is less than 10 lb. The loop is rotatable through 360°.

D.F. Using Cosine Diagram. The simplified circuit for D.F. is shown in Fig. 415 (*a*), the frame connection being unusual in that since the loop has only two turns, a very high step-up transformer, with a voltage ratio of the order of 1 : 1,000, is used for coupling to the first valve. There are three R.F. screened grid stages, with gain control on the screen voltage, a grid detector stage with separate oscillator for C.W. reception, and two L.F. amplifiers. In the use of the receiver when homing, auto-gain is also incorporated, but this is out of action when using D.F. (See page 134 re auto-gain.)

The auxiliary aerial is used through a differential condenser for zero sharpening, but not for sense determination.

Homing. Aural Indication. The principle of aural equi-signal homing with this apparatus is the same as that already described on page 504. For setting a homing course, the loop is adjusted by control No. 8 in Fig. 413 whilst control No. 6 is set to the A/N indication. The circuit connections are shown in Fig. 415 (*b*), which can be followed by a reference to Fig. 396.

Homing. Visual Indication. The circuit for this method is given in Fig. 415 (*c*) and reference should be made to page 505 and Fig. 397. Note that control No 6. in Fig. 413 is shown in the position for visual indicator homing.

Sense Indication. It was mentioned above that sense is not provided with the D.F., but the 180° ambiguity is eliminated when using the indicator by the method described on page 509. The rule, in this case, is that on swinging the aeroplane off its homing course, the first deflection of the indicator pointer will be in the *opposite* direction to that steered, when the transmitter is *ahead*. The process is simplified by pairs of suitably coloured arrows above the visual indicator and on the transparent disc of the loop control, as seen in Fig. 413.

Fig. 416 shows the remotely controlled receiver, which can be mounted up to 8 feet 3 inches distant from the loop.

Remote Control Apparatus. The details of the control apparatus of Fig. 413 are as follows :

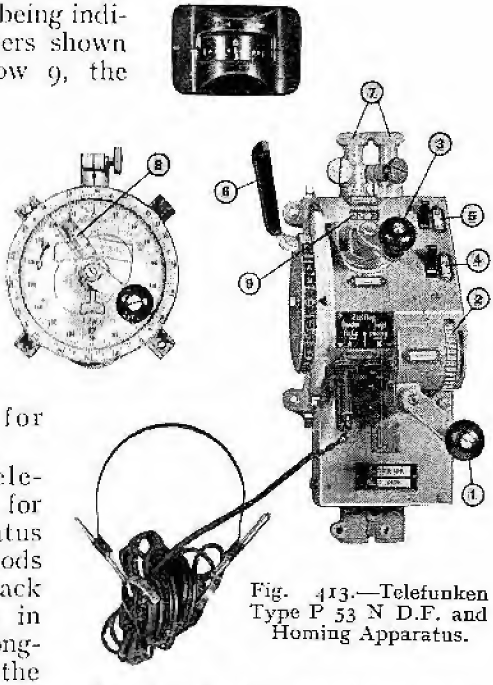


Fig. 413.—Telefunken Type P 53 N D.F. and Homing Apparatus.

(1) Wave range control for receiver, the setting being indicated by the numbers shown in the small window 9, the actual wave length being found by reference to a table.

(2) Output strength control to telephones.

(3) Zero cleaning adjustment.

(4) ON - OFF switch.

(5) Oscillator for C.W. reception.

(6) Ship's "Telegraph" type switch for setting the apparatus for the various methods of reception. The black designations visible in front are for the long-wave range, and the corresponding white ones, for the shorter wave range, are on the far side of the disc. The driven disc can be seen in Fig. 416.

(7) Anchorage for the ends of the flexible shafts used for zero cleaning and tuning.

(8) The loop control is by a flexible drive, and carries, on an extension of the handle, a transparent radial scale marked between the limits +20°, 0° −20°. On the dial can be seen a curve, which is also visible through the radial scale, and intersects it at a reading which corresponds to the quadrantal or other correction for that direction of the loop.

R.C.A. MANUFACTURING COMPANY, INC. TYPE AVR-8 AIRCRAFT RADIO COMPASS

This equipment is supplied either in the form of a simple homing device with fixed loop, or as a radio compass with rotating loop, whilst the controls for the loop rotation, receiver tuning, frequency band change and the switch panel may either be separately mounted as in Fig. 417, or combined on a single large panel. In every case the visual indicator is separately mounted.

Frequency Range. The tuning range covers the Radio Range Beacons, Broadcasting and Aircraft Communication bands of the U.S., namely, 200–410 kc. (1,500–732 m.), 550–1,500 kc. (545–200 m.) and 2,200–6,700 kc. (136–45 m.). Band switching is done by the unit indicated in Fig. 417, using flexible drives to the receiver unit and also to the base of the loop.

Circuit. The simplified circuit is shown in Fig. 418, and includes the method of valve switching described on page 507 for reversing the phase of the loop e.m.f., at audio frequency, before combining it with the auxiliary aerial e.m.f. This was seen to result in an audio-

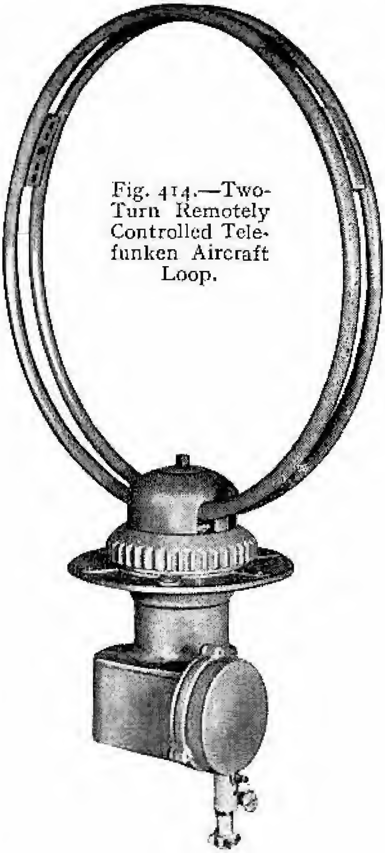


Fig. 414.—Two-Turn Remotely Controlled Telefunken Aircraft Loop.

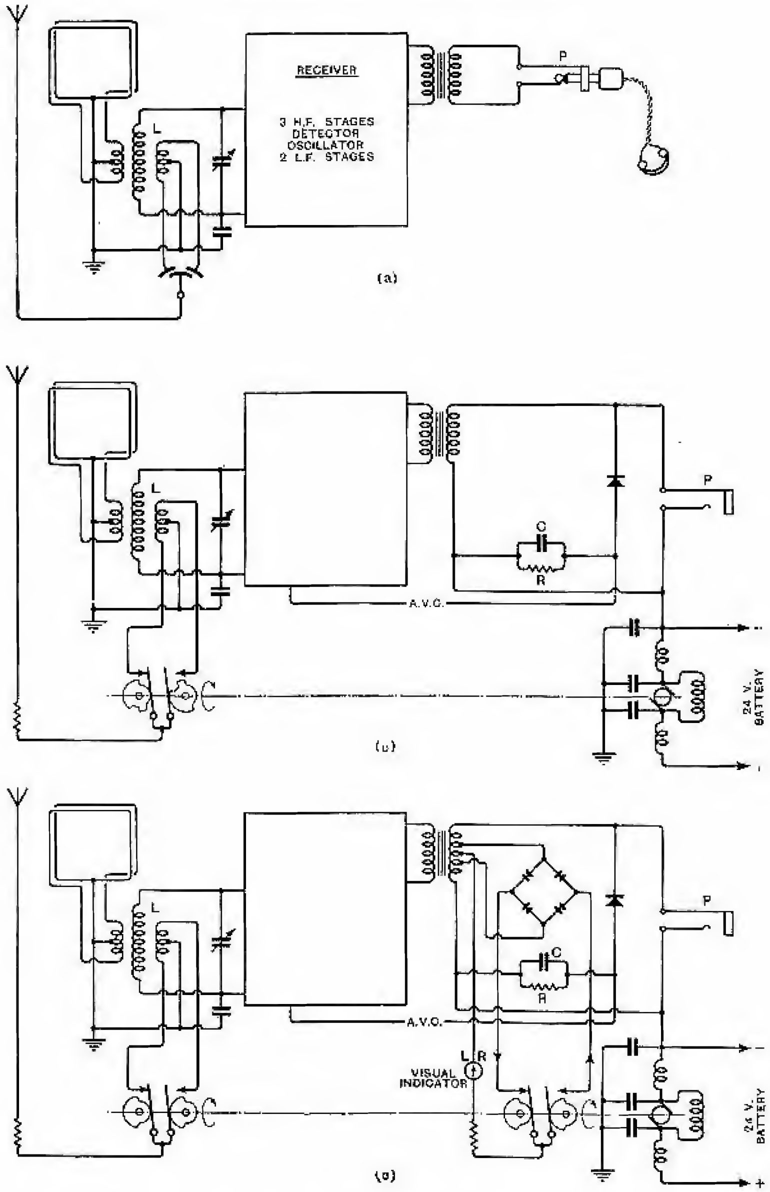


Fig. 415.—Simplified Circuit Connections of Telefunken Equipment of Fig. 413. (*a*) D.F., (*b*) Aural Homing, (*c*) Visual Indicator Homing.

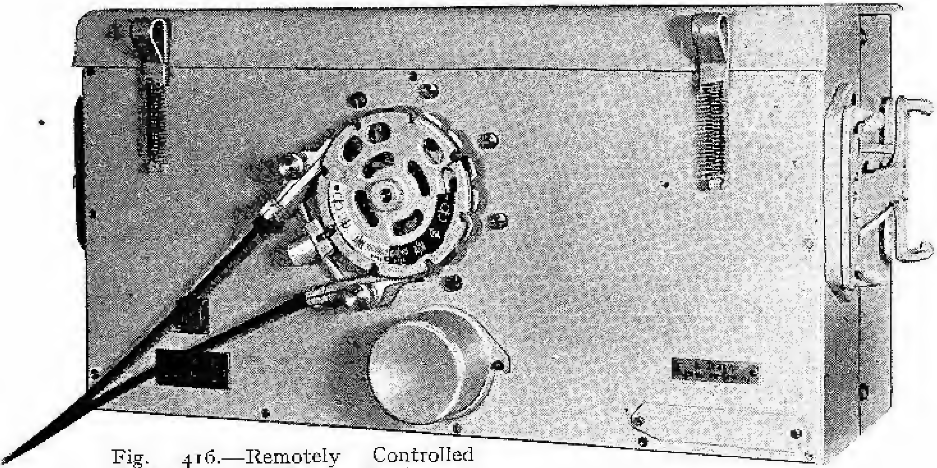


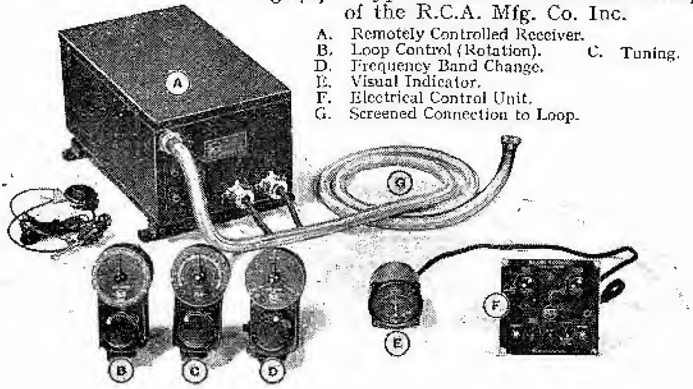
Fig. 416.—Remotely Controlled Receiver for Telefunken Equipment of Fig. 413.

frequency output from the radio receiver, alternate half cycles of which are proportional to the polar ordinates of the two cardioids of Fig. 395, the phase of the audio signal being also reversed as the loop passes through the position of cosine minimum, which coincides with the equi-signal direction.

In this case, the audio frequency is 95 cycles per second and is applied to the transformer T_1, one secondary winding L_1 of which provides the switching e.m.f. whilst the output of the split secondary L_2L_2 is rectified by the full wave rectifier R, and applies balanced pulsating D.C. voltages, alternately in one direction and the other, across the D.C. microammeter.

Fig. 417.—Type AVR-8 Aircraft Radio Compass of the R.C.A. Mfg. Co. Inc.

A. Remotely Controlled Receiver.
B. Loop Control (Rotation). C. Tuning.
D. Frequency Band Change.
E. Visual Indicator.
F. Electrical Control Unit.
G. Screened Connection to Loop.



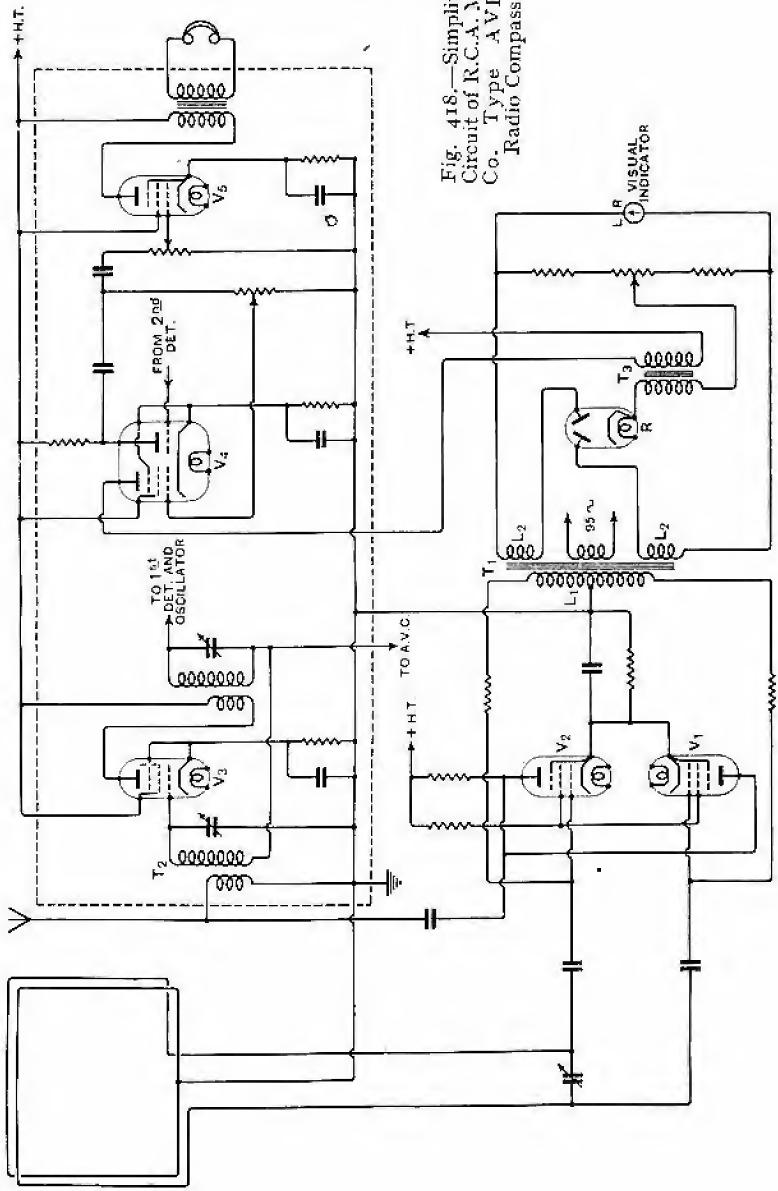


Fig. 418.—Simplified Circuit of R.C.A. Mfg. Co. Type AVR-8 Radio Compass.

The damping of the meter is such that, under these conditions, the pointer maintains a steady central position.

The 95-cycle output of the amplifier V_4 is, however, applied to the transformer T_3, and, according to the phase of this output, will increase the rectified current during one half wave and reduce it during the next half wave and so on, producing unbalance of the D.C. voltages across the meter, and hence a deflection. The direction of this deflection will accordingly be governed by the direction in which the loop is turned from the equi-signal position, and the amplitude of the deflection by the angle between the plane of the loop and the vertical plane of the wave front.

Audio reception with volume control independent of the visual indicator is provided by V_5, and other minor controls will be noted in the circuit drawing.

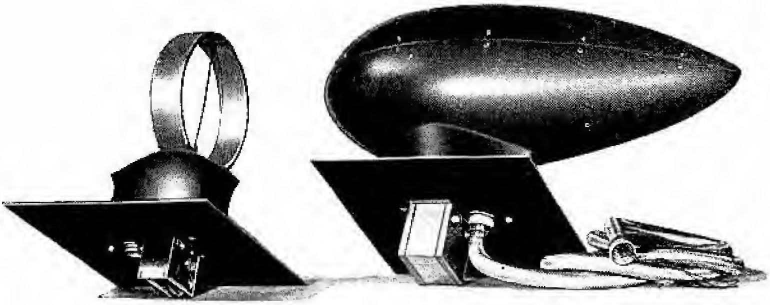


Fig. 419.—Rotating Loop and Housing for R.C.A. Mfg. Co. Type AVR-8 Radio Compass.

Rotating Loop. The loop is shown in Fig. 419, the litz wound coil being 8 inches diameter and enclosed in a bakelite streamlined housing. The dynamic drag is about 3·7 lb. at 160 m.p.h. and its weight complete 11¾ lb. The overall length of the shield is 24 inches, and the overall height above the mounting plate 12⅝ inches.

Fig. 420 shows the gear box beneath the loop, which includes two sets of worm drive, one for the loop rotation and the second for the loop wave band switch which is cam operated. The general layout is seen in Fig. 421.

Receiver. The receiver, apart from the switching valves and 95-cycle oscillator, comprises an R.F. Pentode stage, a Pentode-Triode first Detector Oscillator, an R.F. Pentode I.F. stage, a Double Diode Pentode I.F. second Detector, a Triode Pentode for control of the 95-cycle output from the amplifier to the visual indicator circuit, and a Pentode output for telephones.

Power Supply. The equipment operates from the aircraft 12-volt battery and has a Powertron vibrator for H.T. supply. This is included in the receiver unit, the dimensions of which are $16\frac{1}{8}$ inches × $9\frac{7}{8}$ inches × $7\frac{3}{8}$ inches, and its weight is $30\frac{3}{4}$ lb.

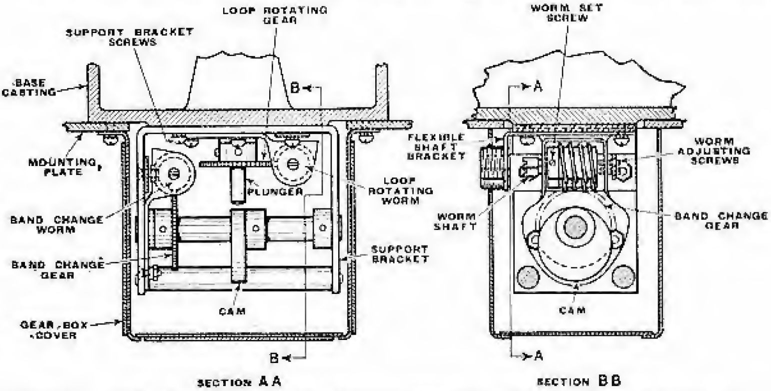


Fig. 420.—Details of Drive and Wave Range Switching of Loop of Fig. 419.

STANDARD TELEPHONES AND CABLES, LTD. TYPE R.9. AIRCRAFT D.F. AND HOMING RECEIVER

This installation is designed primarily for civil aircraft, and provides, in a compact form, D.F. and Homing facilities, with aural or visual indication.

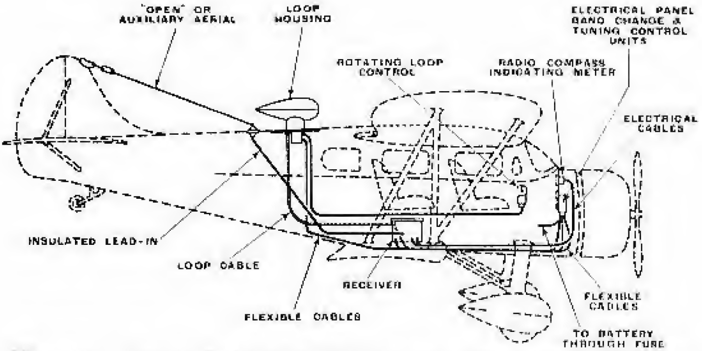


Fig. 421.—General Layout of Equipment of AVR-8 Radio Compass of R.C.A. Mfg. Co. Inc.

The visual indication for homing is by means of two neon tubes, mounted in the slot shown in the receiver panel in Fig. 422. These tubes are normally set so that they glow to about half their length, under which conditions a movement of the aircraft from its course will cause one light beam to lengthen and the other to shorten.

An advantage claimed for neon tubes over the centre zero meter is their comparative immunity from interference by static or when homing on a transmitter which is working morse. Whilst causing erratic flashing of the tubes, these two causes of considerable trouble with the centre zero meter do not interfere with the true indication of the neon tubes in the steady signal intervals, since the light beams have no inertia.

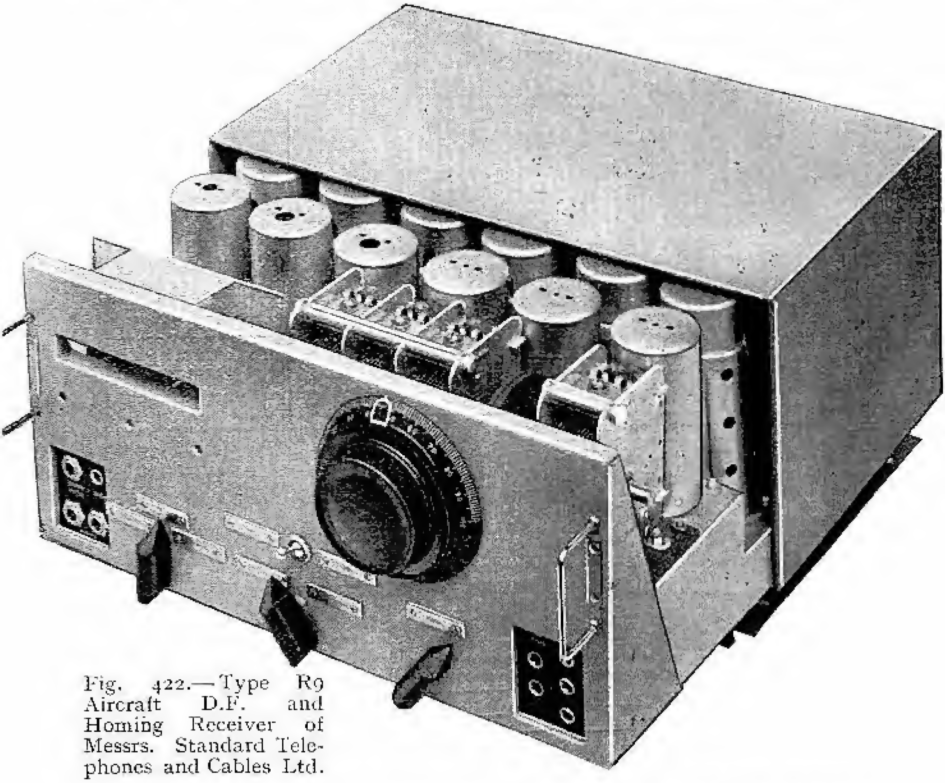


Fig. 422.—Type R9 Aircraft D.F. and Homing Receiver of Messrs. Standard Telephones and Cables Ltd.

The rotating loop has a diameter of only $3\frac{1}{2}$ inches, and is mounted inside a small streamlined housing of the type shown in Fig. 419.

Circuit. The principle of this equipment is that of the valve switched cardioids, as described on page 507, although the method used to obtain visual indication is somewhat different. A simplified circuit diagram is given in Fig. 423 where L is the loop, tuned through the dust core high-frequency transformer T_1, by the condenser C_1. The loop oscillatory circuit is connected across the grids G_3 of the two heptodes V_1 and V_2, the anodes of which are strapped and taken to the input of a superheterodyne receiver and low-frequency amplifier. An open aerial with variable damping and tuning is also connected to this anode lead.

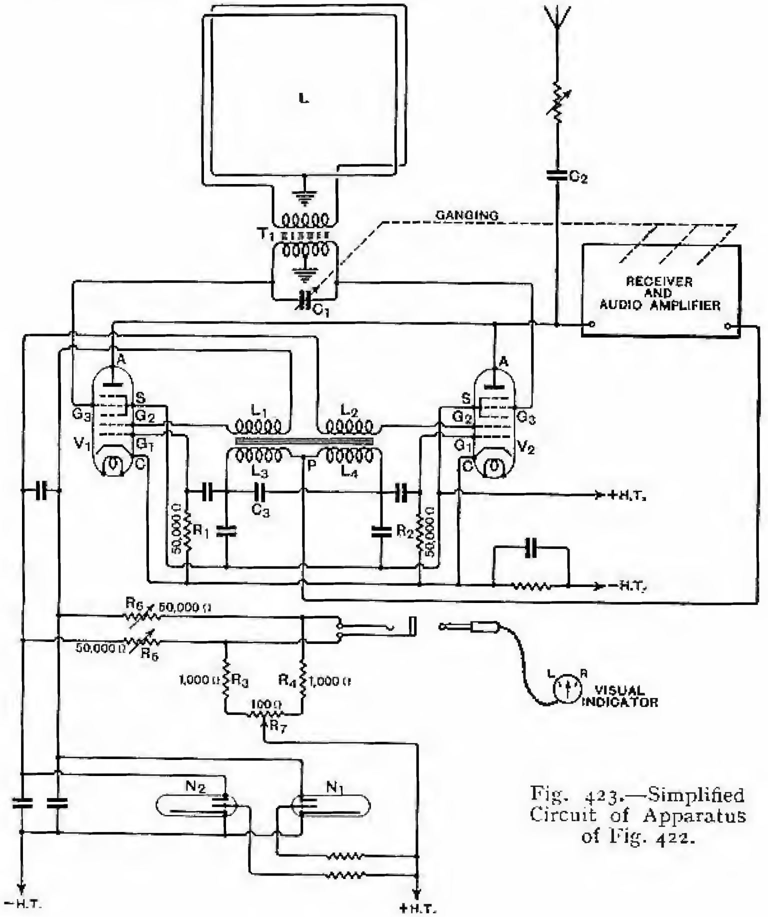


Fig. 423.—Simplified Circuit of Apparatus of Fig. 422.

The triode portions of V_1 and V_2 (C, G_1 and G_2) are used in an oscillator circuit, of which L_3 L_4 C_3 comprise the grid circuit and L_1 L_2 the reaction coils. The frequency of this circuit is 100 cycles and the electron streams of the heptodes are modulated at this frequency, thus rendering the tetrode sections (C, S, G_3, A) of V_1 and V_2 alternately operative. Modulation is therefore applied to the signal e.m.f.'s, and it has already been explained on page 507 how the phase of the low frequency output of the amplifier is a function of that of the loop signal, and hence of the relation between the axis of the loop and the direction of the received signal.

In the present case, the output is brought back to the mid-point P of the grid coil of the oscillator and here produces unbalance in the latter circuit. Suppose the phase of the output to be the same as that of the G_1 grid circuit e.m.f. of V_2; there results an increase in the grid current in the resistance R_2, and a consequent increase in bias on the G_1 grid of this valve. This reduces the G_2 circuit current (this being the anode circuit of the oscillator) of V_2 and increases the G_2 current of V_1. The volts accordingly rise in R_5 and fall in R_6, these changes causing the neon tube N_2 to glow more brightly and N_1 to cut down.

A jack is supplied for the centre zero indicator, and a potentiometer R_7 serves for zero adjustment and for balancing the neon tube brilliancy.

Receiver. The receiver covers a frequency band of 1,400 to 150 kc. (214 to 2,000 m.), and, owing to the use of multi-purpose valves, measures only 12 inches × 7 inches × 6 inches. The tetrode sections of the switching heptodes give a high voltage step up to the loop signal, and are followed by a band pass second channel filter and a heptode frequency changer. There is a tetrode I.F. amplifier, and a double diode triode for I.F. detection and auto-gain control. If desired, the output from this point may be taken back to the switching valves in the manner already described, or alternatively a second frequency change and further amplification may be employed.

The selectivity is such that the signal falls 35 to 40 db. (to $\frac{1}{50}$th or $\frac{1}{100}$th voltage) for a 5 kc. detune from mid-band frequency, and when used for communication purposes, on a trailing aerial of 9 metres effective height, the sensitivity is sufficient to provide 1 milliwatt output in the telephones from a signal of 5 μv/m, modulated 30%.

The high-tension supply is from a rotary transformer, and low tension from the 12-volt or 24-volt aircraft battery.

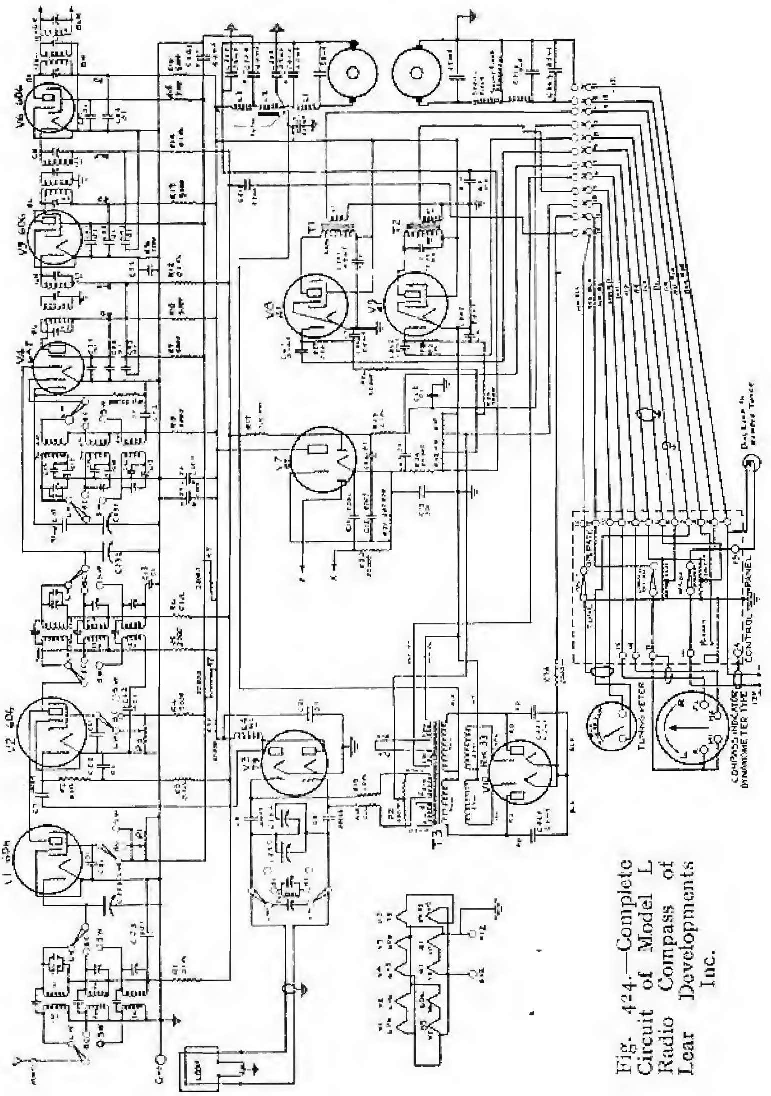


Fig. 424.—Complete Circuit of Model L Radio Compass of Lear Developments Inc.

LEAR DEVELOPMENTS INC. MODEL "L" RADIO COMPASS-RECEIVER

The radio compass described below has much in common with the two equipments just mentioned, again employing valve switching or modulation of the loop signal, and using alternatively an A.C. dynamometer (page 507) or a D.C. centre-zero meter for indication.

Circuit. In the previous descriptions of commercial equipments simplified circuit diagrams have been prepared, in order that the principles of their action should not be made difficult to follow by a complexity of wiring and accessory apparatus. As the principle of this circuit may be assumed to be fairly well understood at this stage, complete circuit connections have been reproduced in Fig. 424 which includes the dynamometer type of compass indicator.

The double triode V_{10} is in a push-pull oscillator circuit, the anode coils of which form the primary of the transformer T_3. From a secondary winding of T_3, 105-cycle modulation is applied to the grids of the double triode V_3 to which the tuned loop is also connected.

The output of these balanced modulators V_3 is taken through a buffer valve V_2, in the anode circuit of which it is combined with the open aerial signal. The open aerial is inductively coupled to a tuned circuit which provides selectivity and also the correct phase relation to produce a cardioid when combined with the loop signal. The pentode V_1 serves to amplify the signal and also to prevent stray open aerial coupling to the balanced modulators.

The combined outputs of V_1 and V_2 are coupled through a selective circuit to the frequency converter V_4, which is followed by a two-stage amplifier on the intermediate frequency of 487·5 kc. The double diode triode V_7 rectifies the intermediate frequency and provides the first stage of amplification for an amplified A.V.C. A 0–100 microammeter in the diode detector circuit facilitates tuning and, after experience of a route, may be used as a fair estimate of distance covered.

Dual Output Stages. Two parallel output pentodes are used, one of which (V_8) has a plate circuit transformer with wide frequency response connected to jacks for two telephone head sets. The V_9 output transformer has a primary sharply tuned to the modulator frequency of 105 cycles, and its impedance ratio matches the dynamometer circuit. The tuning of the circuit tends to eliminate pointer vibration in the meter, due to modulation frequencies from the transmitting station.

A manual control of the input of each of the above valves provides independent adjustment of both audio signal strength and the dynamometer signal. These potentiometers are seen on the control panel, the audio control having an associated " on-off " switch, and the dynamometer sensitivity potentiometer a switch to turn on the audio oscillator for compass operation.

Receiver sensitivity is normally looked after by the A.V.C., but a manual control is supplied in some models for use when flying a long range equi-signal beacon course, in which circumstances it is found to give better results.

Apparatus. The components are shown in Fig. 425 and include a 20-inch diameter loop, the body of which is streamlined and covered with linen tape which has a coating of either transparent nitrate dope or non-metallic paint. The base support is an aluminium casting from which a 12-foot screened cable runs to the receiver chassis.

Control Panel. This contains the two volume controls and switches P and C, the telephone jacks, a " Tune-Operate " switch S and a Tuning Meter.

The Tune-Operate switch changes the time constant of the A.V.C. circuit, the time being short for tuning purposes and long for compass operation when abrupt changes of receiver gain are not required.

A 20-foot cable runs from the control panel to the receiver chassis and 10-foot cables to the batteries and the Course Meter CM.

Course Meter. As already mentioned, this may be either a D.C. or an A.C. instrument. In the former case, a Weston centre-zero microammeter with special damping is used, and an associated rectifier circuit is connected in much the same way as in Fig. 418. The above is the more normal arrangement but in certain cases a Hickok two-winding air core dynamometer is used, as illustrated in the circuit diagram.

It should be noted that in either case the meter is connected so as to deflect *left* when the aircraft turns *left* with the transmitter ahead.

Remote Control Head. In this unit, an aluminium casting carries the wave band selection and the tuning controls BC and TC with their respective dials, sectors of which can be seen through suitable apertures. Two 15-foot lengths of remote control cable drive are supplied which operate the tuning condensers and range switch through worm drives.

Frequency Range. The frequency range when using the compass is 195–415 kc. (1,538–723 m.) and 550–1,500 kc. (545–200 m.). There is an additional short-wave band for open aerial reception only, from 2,800–7,700 kc. (107–39 m.).

Selectivity. At signal frequencies of 300 and 1,000 kc., the image signal is 80 db. down on the main signal (1/10,000th voltage). Transmitters separated by 10 kc. from the signal to which the receiver is tuned, are attenuated more than 60 d.b. (1/1,000th voltage).

Sensitivity. Full output, with compass indication to an accuracy of 1°, can be obtained on a field strength of 5 μv/m provided that atmospheric noise level is not unduly high.

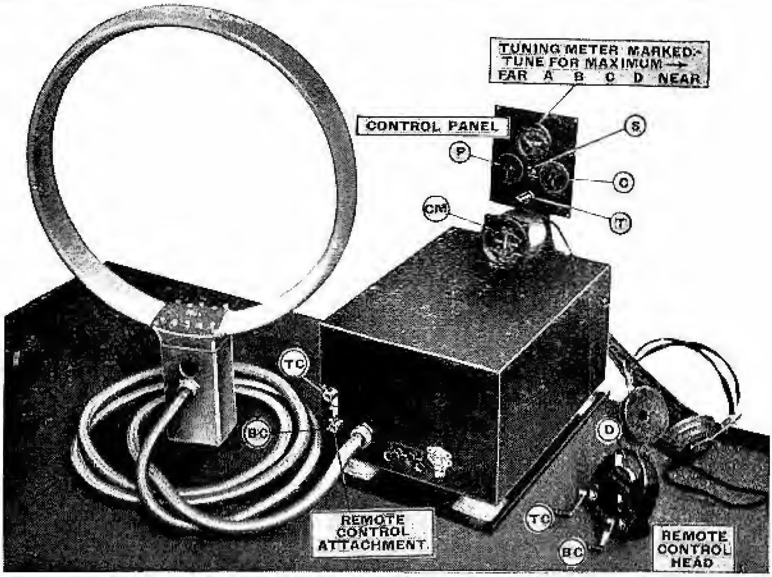


Fig. 425.—Components of Model L Radio Compass of Lear Developments Inc.

Important

The extracts from "Air Publication 1529. The "Q" Code and other Abbreviations to be used in the Civil Aeronautical Radio Service," also from "The Admiralty List of Wireless Signals" and other official publications, are reproduced here as being of general interest and also for the purposes of examples, but, being liable to alteration, they MUST NOT ON ANY ACCOUNT BE USED FOR NAVIGATION WITHOUT CONFIRMATION FROM THE PROPER SOURCES.

CHAPTER 14

DIRECTION AND POSITION FINDING

Introduction. This chapter deals with direction and position finding by means of bearings obtained by the use of coastal or aerodrome ground D.F. stations together with some notes on the duties of the aerodrome D.F. in regard to the control of aircraft.

There follows a discussion of the mobile D.F. installation in the ship or aircraft and the use of wireless bearings as aids to navigation, together with notes on the special uses of this type of D.F. installation in emergencies.

A final section gives brief examples of the application of wireless bearings to everyday navigation problems.

International Regulations for D.F. Service and Procedure. The frequencies to be used by D.F. stations, together with other information appears in section C of Article 30 of the "General Radiocommunication Regulations" that were agreed at the International Telecommunication Convention of 1932. An appendix to these regulations gives the General Instructions and Rules of Procedure and these extracts are now reproduced.* It should, however, be noted that the whole of the matter is liable to revision at the 1938 Convention.

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* By kind permission of The Controller of H.M. Stationery Office.

GENERAL RADIOCOMMUNICATION REGULATIONS, **(Art. 30)**
MADRID, 1932

C. Service of Direction-finding Stations.

§ 9. The Administrations to which direction-finding stations are subject accept no responsibility for the consequences of an inaccurate bearing.

§ 10. These Administrations notify, for insertion in the List of Stations performing Special Services, the characteristics of each direction-finding station, indicating, for each one, the sectors in which bearings are normally accurate. Any change in these details must be published without delay; if the change is of a permanent nature, it must be communicated to the Bureau of the Union.

§ 11. (1) The normal wave for direction-finding is the wave of 375 kc/s (800 m). All coast direction-finding stations must, in principle, be able to use this wave.(1) They must, in addition, be able to take bearings on emissions made on 500 kc/s (600 m.), especially for locating signals of distress, alarm and urgency.

(2) An aircraft station desiring to have a bearing must, in order to ask for it, call on the wave of 333 kc/s (900 m.) or on a wave allotted to the air route on which the aircraft is flying. In all cases where an aircraft, being in the vicinity of coast stations, applies to the latter for a bearing, it must use the frequency on which these coast stations keep watch.

§ 12. The procedure to be followed in the direction-finding service is given in Appendix 13.

APPENDIX 13.

Procedure for obtaining Direction-Finding Bearings.

I. General Instructions.

A. Before calling one or more direction-finding stations, for the purpose of asking for a bearing, the mobile station must ascertain from the List of Stations:

1st The call signs of the stations to be called to obtain the bearings desired.

2nd The wave on which the direction-finding stations keep watch, and the wave or waves on which they take bearings.

3rd The direction-finding stations which, being linked with it by special wires, can be grouped with the direction-finding station to be called.

B. The procedure to be followed by the mobile station depends on varying circumstances. Generally, the following must be taken into account:

1st If the direction-finding stations do not keep watch on the same wave, whether it be the wave on which bearings are taken or another wave, a separate request for the bearings must be made to each station or group of stations using a given wave.

2nd If all the direction-finding stations concerned keep watch on the same wave, and if they are able to take bearings on a common wave—which may be a wave other than the listening wave—they should all be called together, in order that the bearings may be taken by all the stations at the same time, on one and the same transmission.

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(1) It is recognised that certain existing stations are not able to use this wave, but all new stations must be able to take bearings on 375 kc/s (800 m) and 500 kc/s (600 m).

3rd If several direction-finding stations are grouped by means of special wires, only one of them must be called even if all are furnished with transmitting apparatus. In that case, however, the mobile station must, if necessary, specify in the call, by means of the call signs, the direction finding stations from which it wishes to obtain bearings.

II. Rules for Procedure.

A. The mobile station calls the direction-finding station or stations on the wave given in the List of Stations as their listening wave. It transmits the abbreviation QTE, which means:

" I wish to know my bearing in relation to the direction-finding station which I am calling."

or

" I wish to know my bearing in relation to the direction-finding station or stations whose call signs follow."

or

" I wish to know my bearing in relation to the direction-finding stations grouped under your control,"

and the call sign or signs necessary, and concludes by indicating, if necessary, the wave which it is going to use to enable its bearings to be taken. It then awaits instructions.

B. The direction-finding station or stations called prepare to take the bearing; if necessary, they warn the direction-finding stations with which they are linked. As soon as the direction-finding stations are ready, such of them as are provided with transmitting apparatus reply to the mobile station in the alphabetical order of their call signs, by giving their call sign followed by the letter K.

In the case of direction-finding stations which are grouped, the station called warns the other stations in the group and informs the mobile station as soon as the stations of the group are ready to take the bearing.

C. After having, if necessary, changed to its new transmitting wave, the mobile station replies by sending its call sign, together with any other signal needed, for a period sufficiently prolonged to permit the bearing to be taken.

D. The direction-finding station or stations which are satisfied with the operation transmit the signal QTE (" Your bearing in relation to me was .... degrees "), preceded by the time of the observation and followed by a group of three figures (000 to 359), indicating in degrees the true bearing of the mobile station in relation to the direction-finding station.

If a direction-finding station is not satisfied with the operation, it requests the mobile station to repeat the transmission described under C.

E. As soon as the mobile station has received the result of the observation, it repeats the message to the direction-finding station, which then states that the repetition is correct or, if necessary, corrects it by repeating the message. When the direction finding station is sure that the mobile station has correctly received the message, it transmits the signal " end of work." This signal is then repeated by the mobile station, as an intimation that the operation is finished.

F. The particulars of (*a*) the signal to be used to obtain the bearing, (*b*) the duration of the transmission to be made by the mobile station, and (*c*) the time used by the direction-finding station in question are given in the List of Stations.

List of D.F. Stations. A complete list of D.F. Stations is given in " List of Stations Performing Special Services " published by The Bureau of the International Telecommunication Union at Berne. In the section of this list that deals with D.F., are tabulated the following particulars :

(1) Name of the station.
(2) Exact geographical position of
    (*a*) the receiving aerial of the D.F. station.
    (*b*) the transmitting aerial of the D.F. station.
    (*c*) the transmitting aerial of the station mentioned in col. (8).
(3) Call sign.
(4) Wave length (frequency)
    for calling the D.F. station.
(5) for transmitting to the D.F. station the signals necessary for taking bearings.
(6) for transmission of the bearings by the D.F. station.
(7) Power in the aerial of the transmitter.
(8) Name and call sign of the station with which communication must be established if the D.F. station is not equipped with a transmitter.
(9) Charges in francs.
(10) Observations
    (*a*) Sectors in which bearings are normally accurate and references to national and international publications on buoyage.
    (*b*) Hours of service (G.M.T.), etc.

The number of stations in the list is at present about 230, and in addition to the above information there is also given special procedure for use in the case of certain countries.

CROSS BEARINGS AND THE ACCURACY OF A WIRELESS FIX

Case 1. Position Line by Means of One Shore D.F. Station. Let Fig. 426 represent an imaginary coast line with a port at P, a bay with islands at X and Y, and a D.F. station at some point A, which has been calibrated so as to read the bearings of the incoming signals in degrees east of true North.

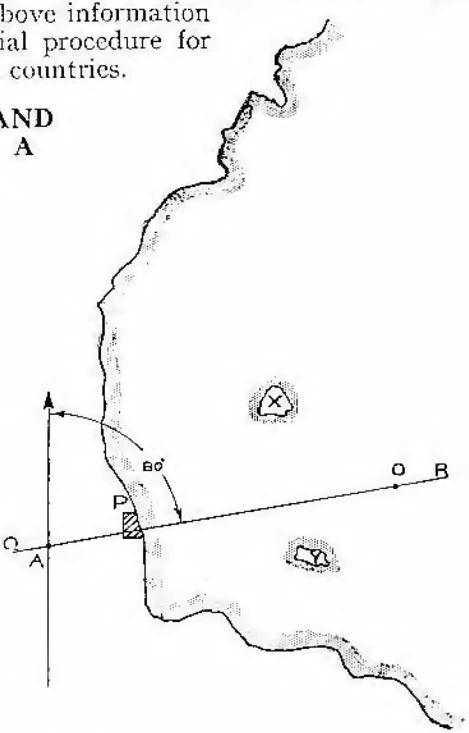

Fig. 426.—Position Line from Single Shore D.F.

Suppose O to be a ship requiring her bearing from the D.F. station at A, the position of which is known to her. The exact wireless procedure to be adopted has been mentioned above and it is assumed that the bearing of the ship is found to be 80° east of North. The telegraphist at the D.F. station, having ascertained this angle or bearing, transmits the result to the ship, and the navigating officer of the ship himself plots out the line Q R on his chart. This line is called a **position line** and is the only information which can be obtained from a single D.F. station.

If the distance of the ship from A is known to be a few miles only, an ordinary nautical chart may be used for plotting the position line, but for distances greater than 100 miles or so a correction for convergency must be applied in the case of a Mercator's chart, or else a gnomonic chart must be used, if the position line is to be accurate.

Case 2. Cross Bearings by Means of Two Shore D.F. Stations. In Fig. 427, the ship O is again approaching the port P and has obtained a position line Q R as before, from the station A. Suppose now, a second D.F. station be placed at B, then by adopting the same procedure as before, a second position line T S will be obtained, corresponding to the bearing of, say, 170°.

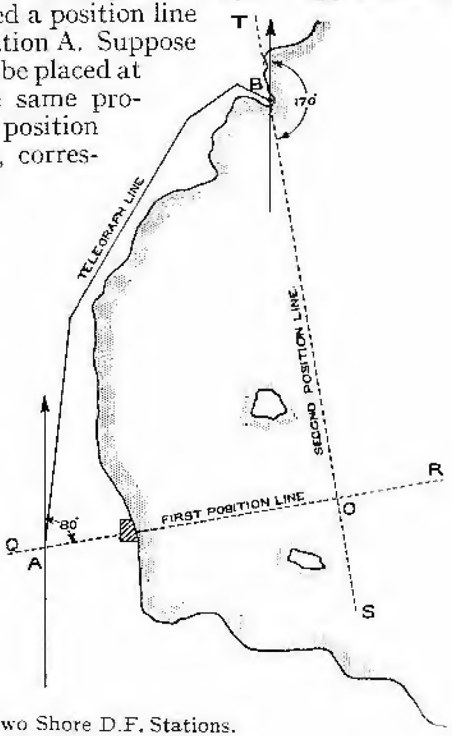

Fig. 427.—Fix from Two Shore D.F. Stations.

The procedure in this case would be much the same as before, except that it would be necessary to include the call signs of both D.F. stations, and also to ensure that both stations took their bearings at the same time. Allowance can be made for any discrepancy in this respect, when using the ship or aircraft D.F. These results would enable the two position lines Q R and T S to be plotted on the chart, and the position of the ship would therefore be found by their intersection. This is called a **Fix.**

The Loth system of twin rotating beacons, described on page 491 provides what amounts to a continuous series of cross bearings.

Case 3. A Fix by Means of Two Associated Shore D.F. Stations. If, instead of being independent stations, A and B are in communication with one another by means of wireless—or, better still, by land wire telegraphy or telephony, in order to reduce the amount of wireless transmission—the work of laying off the two position lines may be done ashore, and the resulting fix transmitted to the ship in the form of a latitude and longitude or else a bearing and distance from a given object, such as a buoy, lightship, or well-known part of the coast. This is a QTF (page 559). On the assumption in Fig. 427 that the station A is a controlling station, and that B is a second D.F. station working in conjunction with A, it is not necessary to know the positions of the two stations, but only the call sign of the controlling station A.

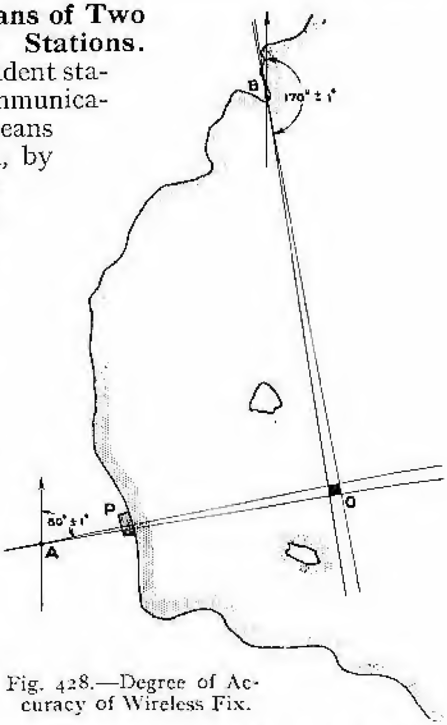

Fig. 428.—Degree of Accuracy of Wireless Fix.

Accuracy. The primary claim for wireless navigation is that it is an emergency method of finding the ship's position when, through one cause or another, other methods partially or totally fail. Intelligently used, the wireless direction finder will give good results, and large errors need not be anticipated; however, it will be of interest to inspect the degree of accuracy which can be expected in a scheme such as that illustrated in Fig. 427.

In Fig. 428 is given some idea of the possible discrepancies between the real position of the ship and that given by a D.F. with an error in the taking of the bearing of 1° either side of the true value. A small quadrilateral has been shown black at the position O, and this represents the area of doubt.

In Fig. 429 the port P is shown on a map drawn to a smaller scale, so that the accuracy of the D.F. fix may be investigated when the ship is at a considerable distance from the stations. The smallest areas are seen to be when the position lines from A and B intersect at right angles, as at O_1. As the angle of intersection becomes more acute, due to the increasing distance of the ship from the stations, as at O_3, or else due to its approaching a position on a line passing through the stations, the area of doubt increases until, when the ship is at some position O_4, it begins to be excessive.

Case 4. A Fix by Means of Three Associated Shore D.F. Stations. Suppose, now, that the case illustrated in Fig. 429 be modified by the addition of a third station at C, as in Fig. 430. The field of accurate work is now greatly increased, since it becomes possible to get position lines from C to intersect those from A and B at such places as O_3 and O_4, the reduction in area of the quadrilateral at O_4 being particularly noticeable. In practice it is customary to use three or more D.F. stations in an important area, so as to give ample checks, one on the other, and also to give the increased accuracy which has just been noticed. During the War of 1914-1918 it was common practice to use four D.F. stations on each area in order that "snap" bearings might be taken with the minimum chance of error (2001).

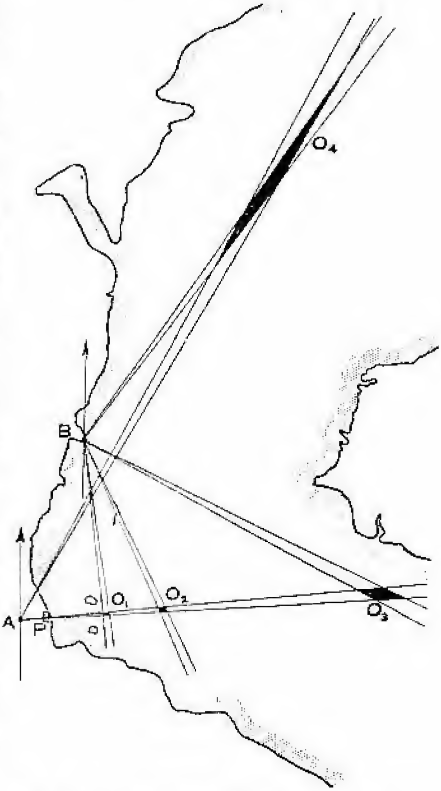

Fig. 429.—Variation in Accuracy of Wireless Fix with Relative Position of Ship and D.F. Stations.

An example of associated D.F. stations engaged in ship work is the North Sea German D.F. Group, details of which are given on page 578.

Similar groups are, of course, in existence for air navigation, the well-known English group being Croydon, Pulham and Lympne, of which Croydon is the control station.

FURTHER OBSERVATIONS ON THE ACCURACY OF A WIRELESS FIX

When employing short waves for D.F., ranges of 1,000 miles may be contemplated and the effect of a comparatively small angular error is to produce doubt of the position of the transmitting aircraft extending over many miles. Errors of ±1° or ±2° must be looked upon as of common occurrence with short-wave D.F., with occasional errors of ±5° upwards, and the effect of these at varying distances is plotted below. There is also given the extent of the area of doubt that occurs in the case of a fix by two position lines (assumed at right angles), when errors of the above amount are believed to be present in each.

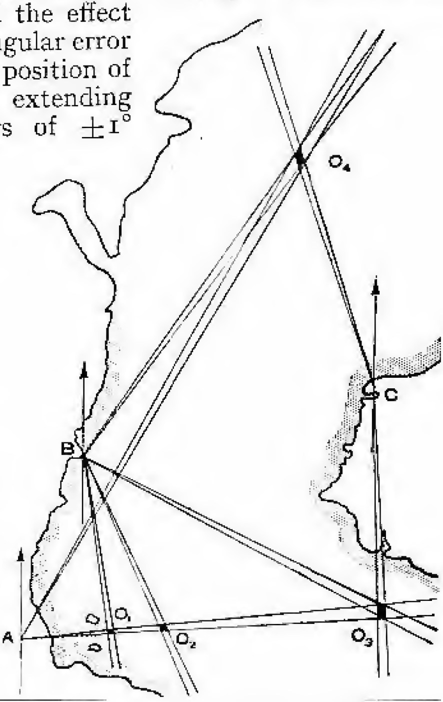

Fig. 430.—Increase in Accuracy of Wireless Fix due to Third D.F.

D.F. Error	Distance	Lateral Error + or −	Area of Doubt
±1°	100 miles	1¾ miles	12 square miles
	500 ,,	8¾ ,,	300 ,, ,,
	1,000 ,,	17½ ,,	1,200 ,, ,,
±2°	100 ,,	3½ ,,	50 ,, ,,
	500 ,,	17½ ,,	1,200 ,, ,,
	1,000 ,,	35 ,,	5,000 ,, ,,
±5°	100 ,,	8¾ ,,	300 ,, ,,
	500 ,,	43¾ ,,	7,600 ,, ,,
	1,000 ,,	87½ ,,	30,000 ,, ,,

It is seen that at 1,000 miles range, the knowledge that a ±5° error may exist means uncertainty of nearly ±90 miles in position, and the critics of the use of wireless as an aid to navigation are fond of pointing out that a fix by two such position lines leaves a doubtful area of 30,000 square miles. Even the more reasonable ±2° error gives, at 1,000 miles, an area of 5,000 square miles.

By comparison with the above figures, however, it is interesting to note the results possible when obtaining a fix by astronomical position lines using a Bubble Sextant in aircraft. This instrument is in principle an ordinary sextant with an artificial horizon, levelled by a bubble, for use when the true horizon is obscured, and under favourable conditious is of remarkable precision. On shore, an astronomical position line can be obtained with an accuracy of about one or two miles.

In the air, however, due to errors produced by the motion of the aircraft, the observational error may on occasion amount to 2° of arc, or 120 nautical miles. Expressing this in the same way as the wireless fix figures, this is ±120, i.e., 240 nautical miles, and the corresponding doubtful area for a fix with similar cross position lines is 76,000 square (statute) miles.

Actually these areas signify little or nothing, except in the case of the necessity for a search in the neighbourhood of a position obtained in such circumstances. More commonly, the lateral distance off course and the distance ahead of or behind schedule are required, and to get these values to within 35 to 50 miles at a range of 1,000 miles is no mean achievement.

There is, however, a means of obtaining far greater accuracy from wireless position lines.

Value of Averaging Observations. On a long trans-ocean flight, routine bearings may be taken every 30 minutes or so and if, instead of taking solitary bearings, a group of ten snap bearings be taken within a space of a few minutes and averaged, there is obtained a surprising increase in accuracy. At long range, the rate of change of bearing will be small so that the mean bearing may be taken as that belonging to the mean time of the group.

In obtaining the average, the important point is that bearings that are " obviously wrong "—that is to say differing from the rest by several degrees—should not be discarded, unless marked as doubtful, when taken. The reason for this is partly because one is not always correct in assuming that any one bearing is faulty and also because experience and calculation both show that the law of averages is able to take account of the bad as well as the good bearings, errors being as likely to be positive as negative.

Actually, it can be shown that if two out of ten readings are rejected as being doubtful ones, the error of the mean bearing will in general be increased due to the fact that only eight instead of ten readings are being averaged.

If a systematic method be worked out on these lines an accuracy of $\pm\frac{1}{2}°$ or better may confidently be expected even though individual errors exceed 4°.

The subject is dealt with in (3605) by P. V. H. Weems in reference to Bubble Sextant Errors in aircraft, methods of organizing a comprehensive system of observation being described in detail. The mean error in a position line obtained in an aircraft from the sun's altitude is shown capable of being reduced, by this means, to about three nautical miles.

STANDARD DEVIATION AND PROBABLE ERROR (CORRECT BEARING KNOWN)

When, in the previous section, the average of a series of bearings is mentioned, the quantity referred to is the Arithmetic Mean, which is given by :—

$$\textbf{Arithmetic mean} = \frac{b_1 + b_2 + \cdot\cdot\cdot\cdot\cdot b_n}{n}$$

where b_1, b_2, etc., are the individual bearings and n the number of bearings in the series. This mean value does not give any indication of the divergence of the individual bearings, although the amount of reliance that can be placed on either the individual or on the mean bearings must depend on this factor.

If, however, the errors of $b_1, b_2 \ldots b_n$ be called $e_1, e_2 \ldots e_n$, then the root mean square value of all these errors is called the Standard Deviation, thus :—

$$\textbf{Standard deviation} = \sqrt{\frac{e_1^2 + e_2^2 + \cdot\cdot\cdot\cdot e_n^2}{n}}$$

and this is a guide to the consistency or otherwise of the bearings in the group.

Having obtained the Standard Deviation, the Probable Error of any individual bearing, that is to say the value of e for which it is as likely that the error will be greater than e as that it will be less than e, is given by the expression :—

Probable error = ±0.6745 × Standard deviation

When a D.F. station is being calibrated by bearings on a known transmitter, the errors in the observed bearings are noted and the Standard Deviation is obtained in the above manner and used as a measure of performance.

STANDARD DEVIATION AND PROBABLE ERROR (CORRECT BEARING UNKNOWN)

In the case of bearings taken for navigation, the errors are, of course, not known, but values of Standard Deviation and Individual Probable Error can still be found, together with the Probable Error of the Arithmetic Mean of a series of observations.

If B be the Arithmetic Mean, then the values $(B-b_1)$, $(B-b_2)$ . . . $(B-b_n)$ are seen to be the differences between the mean and the individual bearings and it can be shown that :

$$\textbf{Standard deviation} = \sqrt{\frac{(B-b_1)^2 + (B-b_2)^2 + \cdots \cdot (B-b_n)^2}{n-1}}$$

$$\textbf{Probable error of any individual bearing} = \pm 0.6745 \times \textbf{Standard deviation}$$

$$\textbf{Probable error of Arithmetic mean bearing} = \pm \frac{0.6745}{\sqrt{n}} \times \textbf{Standard deviation}$$

For further information on this subject, " Higher Mathematics for Students ", by J. W. Mellor (Longmans Green & Co.), may be recommended.

Example. A series of ten successive bearings are logged as in the first column below and it is required to find the Standard Deviation and the Probable Errors.

Bearings in degrees	$(B-b)$	$(B-b)^2$	
71	0.5	0.25	
71	0.5	0.25	$n = 10$
69	1.5	2.25	
74	3.5	12.25	$(n-1) = 9$
72	1.5	2.25	
67	3.5	12.25	
66	4.5	20.25	
72	1.5	2.25	
70	0.5	0.25	
73	2.5	6.25	
705		58.5	

Arithmetic Mean Bearing $= \frac{705}{10} =$ . . . . . $70.5°$

Standard Deviation $= \sqrt{\frac{58.5}{9}} =$ . . . . $2.55°$

Probable Error of any Individual Bearing $= \pm 0.6745 \times 2.55 = \pm 1.72°$

Probable Error of Arithmetic Mean Bearing $= \pm \frac{0.6745}{\sqrt{10}} \times 2.55 = \pm 0.54°$

DUTIES OF THE AIRCRAFT GROUND D.F. STATION

The great increase in flying during recent years has led to corresponding progress in the wireless organization of airports. Furthermore, the advance in the technique of blind flying has greatly increased the demands for D.F. services owing to the number of aircraft that keep to their schedules during bad visibility. On the other hand, the increasing number of marine transmitting beacons, combined with the installation of the D.F. in ships, has prevented anything approaching a corresponding extension in coastal D.F. work, so that it will be preferable to consider the aircraft case.

The duties of the Aircraft D.F. Station differ from those of the Coastal D.F. in that whilst the latter is more often called upon for isolated bearings during thick weather only, and in many cases knows little of the subsequent progress of the ship, the aircraft D.F. may keep in touch with machines over long distances. Further than this, the Control Station of a group of aircraft D.F. stations will itself usually be situated at an important airport and, in addition to passing information regarding bearings and positions, will also send meteorological data, the whereabouts of other aircraft, barometric altimeter checks, etc., and will handle communications directing the landing of the aeroplanes at the local aerodrome.

As a result of this, an extensive list of abbreviations has accumulated for the use of civil aircraft and the current edition of Air Publication 1529, which appears under the title of :— " The ' Q ' Code and Other Abbreviations to be Used in the Civil Aeronautical Radio Service," contains the following sections :—

I. The " Q " Code.
II. Miscellaneous Abbreviations.
III. International Morse Code.
IV. Service Signals.

The " Q " Code. This is an extension of the " Q " code well-known in ship communication and is divided into four sections which are :—

(1) Reciprocal Recognition between Stations.
(2) The Radio Service.
(3) Radio Operation.
(4) The Operation and Control of Aircraft.

Of these, the section that is of most interest in connection with the work of the D.F. Control is the last, and this is again subdivided as follows :—

- (*a*) Movements of Aircraft.
- (*b*) Reports during flight.
- (*c*) Radio Navigation.
- (*d*) Meteorological advice during flight.
- (*e*) Controlled Zones.
- (*f*) Landing Procedures.
- (*g*) Aerodromes.
- (*h*) Danger.
- (*i*) Assistance.

A copy of the latest issue of this publication should be in the hands of everyone interested in aircraft D.F. and a perusal of Section 4 of the " Q " Code will give an excellent idea of this branch of the duties of the Aircraft D.F. Control Station. Sub-sections (*c*), (*e*), (*f*) and part of (*d*) as well as those of the " Miscellaneous Abbreviations " that apply to D.F. work are quoted* below and mentioned in more detail later.

Extracts from " The ' Q ' Code and other Abbreviations to be used in the Civil Aeronautical Radio Service."

(4) The Operation and Control of Aircraft

Abbreviation	Question	Answer or Advice
	(c) Radio Navigation (i) *General*	
QDO	Will you ask station .... to transmit its call sign followed by a continuous dash for ...... minutes, on its working wave (or on the wave of ...... m.) so that I may use my D F apparatus ?	I will ask station ...... to transmit its call sign followed by a continuous dash for ...... minutes on its working wave (or on the wave of ...... m.) so that you may use your D F apparatus.
QFS	Place the radiobeacon at ...... in operation.	The radiobeacon at ...... will be in operation in ...... minutes.
QTG	Will you send your call for fifty seconds followed by a dash of ten seconds on ...... kc/s (or ...... m) in order that I may take your bearing ?	I will send my call sign for fifty seconds followed by a dash of ten seconds on ...... kc/s (or ...... m) in order that you may take my bearing.
	(ii) *D/F bearings*	
QTE	What is my true bearing in relation to you ? or What is my true bearing in	Your true bearing in relation to me is ...... degrees. or Your true bearing in relation

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* By kind permission of The Controller of H.M. Stationery Office. See important notice on page 546.

Abbreviation	Question	Answer or Advice
	relation to ...... (call sign) ? or What is the true bearing of ...... (call sign) in relation to ...... (call sign) ? (*True bearing.*)	to ...... (call sign) is.... degrees at ...... (time). or The true bearing of .... (call sign) in relation to ...... (call sign) is ...... degrees at ...... (time)
QUJ	Will you give me the true course to steer with zero wind to reach you ? or What is the true course to steer with zero wind to reach you or to reach ...... ? (*True reciprocal bearing.*)	The true course to steer with zero wind to reach me is ...... degrees at ...... (time). or The true course to steer with zero wind to reach me or to reach ...... is ...... degrees at ...... (time).
QDL	Do you intend to ask for a series of bearings ?	I intend asking for a series of bearings.
QDM	What is the magnetic course to steer, with zero wind, to reach you (or ......) ? (*Magnetic reciprocal bearing.*)	The magnetic course to steer with zero wind, to reach me (or ......) is ...... (degrees) at ...... (time).
QDR	What is my magnetic bearing in relation to you (or to ......) ? (*Magnetic bearing.*)	Your magnetic bearing in relation to me (or to ......) is ...... (degrees) at ...... (time).
	(iii) *D/F positions*	
QTF	Will you give me the position of my station according to the bearings taken by the direction-finding stations which you control ?	The position of your station according to the bearings taken by the direction-finding stations which I control is .... latitude ...... longitude (or by any other way of showing it).
QGE	What is my position in terms of true bearing and distance from your station ?	Your position in terms of true bearing and distance from my station is ...... degrees (true) ...... kms.
QGF	Will you give me my position in relation to your station (or to ......) expressed as the magnetic course to steer with zero wind, and the distance ?	Your position in relation to my station (or to ....) expressed as the magnetic course to steer with zero wind, and the distance, is ...... degrees ...... km.
QTM (*a*)	Send radioelectric signals and submarine sound signals to enable me to fix my bearing and my distance.	I will send radioelectric signals and submarine sound signals to enable you to fix your bearing and your distance.

(*a*) Principally used by shipping.

Abbreviation	Question	Answer or Advice
(d) Meteorological advice during flight		
(ii) *Barometric pressure*		
QFE	Can you give me the present barometric pressure, not reduced to sea-level, at the surface of ...... aerodrome (name of aerodrome) (*b*). *Example:* QFE? Lyons.	The present barometric pressure, not reduced to sea-level, at the surface of ......aerodrome (name of aerodrome) is ...... (mb. or mm.)(*b*). *Example:* QFE Lyons 973.7.
QFD	My altimeter was adjusted at ...... (aerodrome of departure) at ...... (time of departure, stating whether G.M.T., C.E.T., etc.). Give me the altimeter correction for ...... (name of aerodrome or other place at which the altimeter reading should be correct. *Example:* QFD? Brussels 1030 C.E.T. Paris?	At ...... (name of aerodrome or other place where the altimeter reading should be correct) you must: add ...... metres to the altimeter reading subtract ...... metres from the altimeter reading. *Example:* QFD Paris add 70 metres.
QFF	What is the actual barometric pressure, reduced to sea-level, at ...... aerodrome? (mm. or mb.).	The actual barometric pressure, reduced to sea-level, at ...... aerodrome is ...... (mm. or mb.).
QUH	Will you give me the present barometric pressure at sea-level?	The present barometric pressure at sea-level is ...... (units).
(e) Controlled Zones		
QBI		The fog regulations are in force. (*c*)
QGL	May I enter the controlled zone (zone of approach)?	You may enter the controlled zone (zone of approach).
QGM		You may not enter the controlled zone. or Leave the controlled zone.
QGN	May I land at ......?	You may land at ......
QGO		You may not land at ......
QGP	What is my turn for landing?	Your turn for landing is .....
QGQ		Wait for instructions and remain at a height of ...... metres* in the vicinity of ......

(*b*) The actual pressure must be given to within 1/10th of a millibar and must be the pressure recorded on the ground. The reading of the mercury barometer should therefore be corrected taking into consideration the instrumental correction, the thermometric correction and the height of the barometer above the surface of the aerodrome.

(*c*) QBI followed by the group FIN indicates the suspension of the fog regulations.

* See footnote, page 561.

ABBREVIATION	QUESTION	ANSWER OR ADVICE
QGK		Fly (I am flying) in such a manner that your (my) true bearing in relation to ...... (place) is maintained at ...... degrees and at a height of ...... metres.*

(f) Landing Procedures

(i) *By descent through the clouds*

ABBREVIATION	QUESTION	ANSWER OR ADVICE
QGH	May I descend through the clouds, and land, using the normal procedure ?	You may descend through the clouds, and land, using the normal procedure.
QGI		You may not employ the procedure of landing by descent through the clouds.
QFH	May I descend below the clouds ?	You may descend below the clouds.
QBH(*d*)	Are you flying below the clouds ?	I am flying below the clouds at a height of .... metres.*(*e*)

(ii) *By radiobeacon*

ABBREVIATION	QUESTION	ANSWER OR ADVICE
QFS(*f*)	Please place the radiobeacon at .... in operation.	The radiobeacon at .... will be in operation in .... minutes.

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* Where an answer includes an indication of height, the addition of the group " MER " means that the height above sea-level is given, and the group " SOL " that the height above the aerodrome is given. The group " SOL " should only be used in the immediate vicinity of the aerodrome at which the aircraft intends to land.

The indication of height may be substituted by that of the absolute barometric pressure of the corresponding layer of air. In such cases, the value of this pressure must be followed by " MB PRES " when the pressure is given in millibars and by " MM PRES " when the pressure is given in millimetres.

(It should be noted that in all cases where a foreign word is quoted for use as a group, the actual word quoted must be used in practice : translation of the word is not permissible, e.g., the word " SEA " must not be substituted for the group " MER ").

(*d*) The abbreviation followed by the group PART signifies that the type of cloud referred to is scattered cloud.

(*e*) When transmitted by a ground station in the United Kingdom, has the meaning " Fly below the clouds." When transmitted by a ground station in France, has the meaning " I advise you to fly below the clouds " : if this advice is given by the State services, QBH is followed by Y ; if it is given by the representative of the owner of the aircraft it is followed by Z.

(*f*) (i) If there is a possibility of confusion between a navigational radiobeacon and a landing radiobeacon, they can be distinguished by following the abbreviation with the group " NAV " (navigational) or the group " ATT " (landing).

(ii) In the answer, omission of the number of minutes indicates that the radiobeacon is in operation.

Abbreviation	Question	Answer or Advice
QGA	May I land immediately using the radiobeacon signals ?	You may land immediately using the radiobeacon signals.
QGB		You cannot land at ...... using the radiobeacon procedure.
QGC	Can you direct my landing ?	I cannot direct your landing. Remain outside the approach area.
QFU	What is the prescribed direction for landing expressed as the magnetic course to steer for maintaining this direction ?	The prescribed direction for landing expressed as the magnetic course to steer is ...... degrees.
	(iii) *" ZZ " Procedure.*	
QGX	May I land by using the ZZ procedure ?	You may land by using the ZZ procedure.
QGY		You may not land by using the ZZ procedure.
QFG	Am I above the aerodrome ?	You are above the aerodrome.
QTE	What is my true bearing in relation to you ? or What is my true bearing in relation to ...... (call sign) ? or What is the true bearing of ...... (call sign) in relation to ...... (call sign) ? (*True bearing*)	Your true bearing in relation to me is ...... degrees, or Your true bearing in relation to ...... (call sign) is ...... degrees at ...... (time), or The true bearing of ...... (call sign) in relation to ...... (call sign) is ...... degrees at ...... (time).
QDR	What is my magnetic bearing in relation to you (or to ......) ? (*Magnetic bearing*).	Your magnetic bearing in relation to me (or to ......) is ...... (degrees) at ...... (time).
QDM	What is the magnetic course to steer, with zero wind, to reach you (or ......) ? (*Magnetic reciprocal bearing.*)	The magnetic course to steer with zero wind, to reach me (or ......) is .... (degrees) at ...... (time).
QFO	May I land direct ?	You may land direct.

Miscellaneous Abbreviations. Note that only those abbreviations relating to D.F. have been reproduced below.

Abbreviation	Meaning	Abbreviation	Meaning
DB	I cannot give you a bearing, you are not in the calibrated sector of this station.	DF	Your bearing at ...... (time) was ...... degrees, in the doubtful sector of this station, with a possible error of two degrees.
DC	The minimum of your signal is suitable for the bearing.		

Abbreviation	Meaning
DG	Please advise me if you note an error in the bearing given.
DI	Bearing doubtful in consequence of the bad quality of your signal.
DJ	Bearing doubtful because of interference.
DL	Your bearing at ...... (time) was ...... degrees in the doubtful sector of this station.
DO	Bearing doubtful. Ask for another bearing later, or at ...... (time).
DP	Beyond 50 miles, the possible error of bearing may amount to two degrees.
DS	Adjust your transmitter, the minimum of your signal is too broad.
DT	I cannot furnish you with a bearing ; the minimum of your signal is too broad.
DY	This station is two-way, what is your approximate direction in degrees in relation to this station ?
DZ	Your bearing is reciprocal. (*To be used only by the control station of a group of direction finding stations when it is addressing other stations of the same group.*)

All these groups also appear in the International Code used for shipping.

With regard to the extracts from the " Q " code, some of the expressions used have not been met with in earlier chapters, and others raise interesting questions as to the most expeditious ways of getting the desired information and putting it into the form required for forwarding by W/T to the aircraft.

Before analysing this section of the code (page 568), it will perhaps be preferable to consider the methods used for plotting the wireless fix at a control D.F. station.

Cross Bearings and the Error Triangle. When three D.F. stations are operating on an area and the series of bearings has been received at the control station, it will frequently be found, on laying off the position lines on the chart, that they do not intersect at one point but form a small triangle as shown in Fig. 431. This may be due to various causes as follows :—

(1) Carelessness in taking bearings.

(2) Errors inherent in apparatus or due to inaccurate calibration of the D.F.

(3) Polarization errors, coast refraction or lateral deviation.

(4) Discrepancy between great circle and rhumb line bearings when using Mercator's chart.

(5) Bearings not taken simultaneously by all stations owing to misunderstanding and the ship or aircraft having covered a considerable distance in the interim.

The triangle thus formed is often referred to as a **cocked hat** and it is usual, unless the cause is known and can be allowed for, to assume that the required position or fix is at the centre of the triangle and equi-distant from the three position lines. It may be noticed that this is at the centre of the inscribed circle and not at either the " centre of gravity " or at the centre of the circumscribed circle. An exception to this may be made when one of the bearings has been marked as doubtful, or when the distance from the fix to one of the D.F. stations is much greater than to the other two, in which case equal errors in each bearing would clearly produce a greater lateral error on the longer position line. This is illustrated in the example on page 606.

In some cases an arbitrary value is decided upon for the maximum allowable area of the cocked hat, and if the area exceeds this figure, the fix is advised as being " second class."

The choice of the centre of the triangle does not necessarily give a more accurate value for the fix. In Fig. 432, the dotted lines show the bearings of P from the three D.F. stations. An error of $-2°$ in the case of the A and B bearings and of

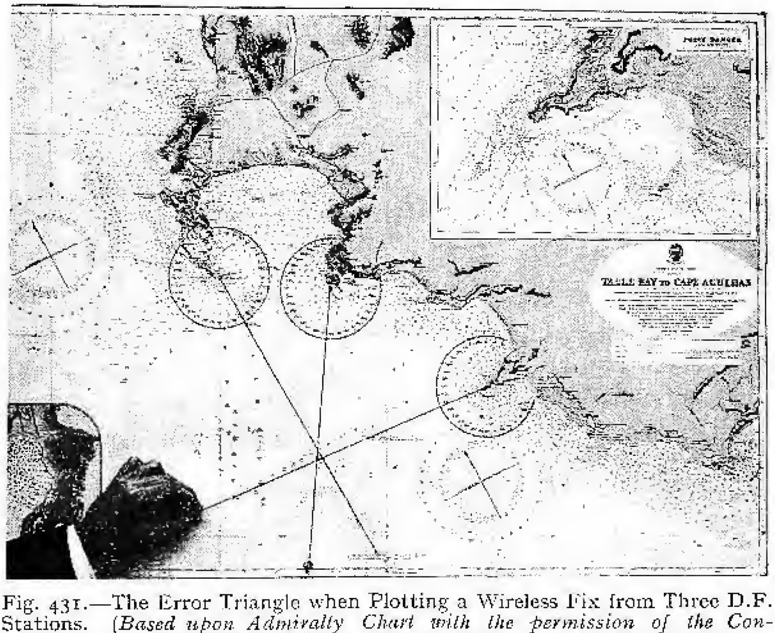

Fig. 431.—The Error Triangle when Plotting a Wireless Fix from Three D.F. Stations. (*Based upon Admiralty Chart with the permission of the Controller of H.M. Stationery Office and of the Hydrographer of the Navy.*) (The D.F. Stations are imaginary ones.)

+2° in the C bearing will give a triangle which, as shown, does not contain the point P at all.

Again, an error of −2° on all three bearings would have given an apparently perfect but incorrect fix near to P′.

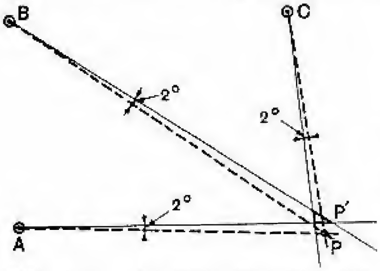

Fig. 432.—The Error Triangle and the Accuracy of a Fix.

In general, however, a large triangle indicates that something is amiss and a small triangle may be taken as being accurate.

Choice of Map for Use at Control Station. The type of chart used on any shore station will depend largely on the conditions under which the station is working. If the station be for accurate observations of an experimental nature, a special gnomonic chart will probably be employed which has its point of contact at the station. The use of such a chart would not be advisable in the case of a group of D.F. stations, since the point of contact could not be at all the stations. An alternative is to have special protractors drawn for each station as in Fig. 467. Actually, it is possible to draw a chart which gives correct azimuths from two points, but only in rare cases would such a chart be considered worth constructing and, in the case of three or four D.F. stations, is ruled out.

For marine work, a Mercator's chart is always available, or, if greater accuracy is required, a special gnomonic chart may be prepared. For aircraft work a map such as the Modified Poly-conic Projection may be used. The 1 : 1,000,000 International Map of the World has been described on page 279, and within the limits of the sheet in use it provides accuracy comparable to that of the gnomonic chart and is easily procurable.

As the 1 : 1,000,000 scale of the International Map is rather small for D.F. work, the operating area of a permanent D.F. station may be redrawn on a larger scale with advantage.

Laying off Position Lines or Bearings. The mechanical arrangements for laying off the bearings should allow the operation to be carried out quickly and accurately and also, for preference, without making marks on the map.

Fig. 431 shows a temporary expedient in which an Admiralty Chart has been used, each D.F. station having its own protractor drawn round it. At the position of each station a pin is inserted, to which is attached a length of black thread ending in a push-pin of the pattern used for photography.

Directly the bearing of the ship is taken at the control station, it is recorded on the map by means of the thread, which is held in position by the pins at either end, and as the bearings taken by the other stations are received at the control, they are also plotted in a similar way. The common intersection, or the centre of the triangle, as the case may be, is then read off, logged and the information transmitted in the proper form. The position may also be recorded on the map, or, more usually, on a separate map as in Fig. 433, in order to keep a check on the relative positions of aircraft in the same neighbourhood.

Such a method of plotting a fix is simple, but the use of pins will soon ruin a map, and the following rather more elaborate system is far preferable.

Fig. 433 shows the Control Tower at the London (Croydon) Airport, with the map in use, and Fig. 434 is a cross section of the board on which the map is mounted. B is a metal bush at the position of one of the D.F. stations, through which passes a black cord having a counterweight arrangement below the board and the free end attached to a lead weight or "mouse." Protractors for the several D.F. stations are drawn round the margin of the map and differently coloured to avoid confusion. Each "mouse" is coloured to correspond to the protractor on which it operates.

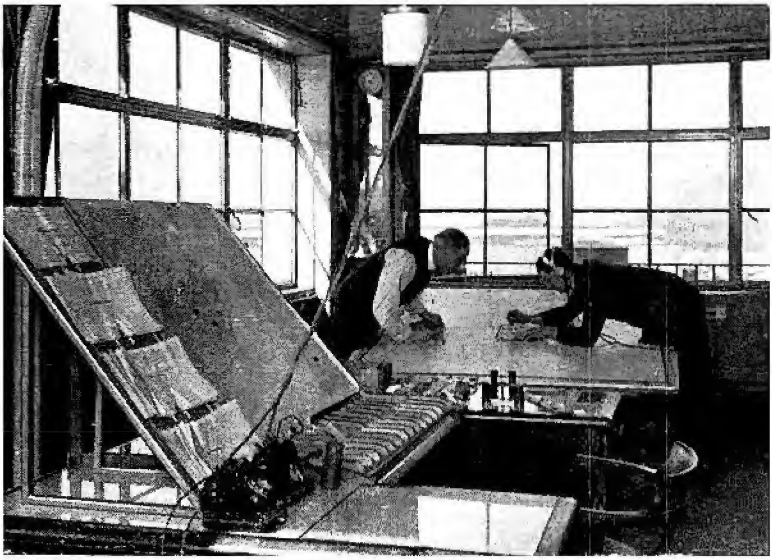

Fig. 433.—Plotting D.F. Bearings in the Control Tower of the London (Croydon) Airport. (*Courtesy of Marconi Co.*)

Checking Distance and Direction from a Point of Reference. After a fix has been obtained for the purpose of furnishing QTF information, a simple way of checking the position of the aircraft relative to a point of reference is to apply dividers and to measure off the distance on the map scale. The compass direction can usually be judged sufficiently accurately without mechanical aid.

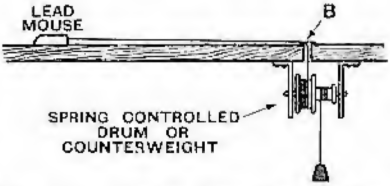

Fig. 434.—Device Used for Plotting Bearings at London (Croydon) Airport.

An alternative method is to construct a transparent protractor on the lines of that suggested in Fig. 435. In use, the centre of the protractor is registered with the point from which a bearing is required, the vertical straight lines being used to ensure that the 0°-180° line is parallel to the nearest meridian so that a true bearing may be read off. Magnetic Variation is applied when necessary.

The concentric circles are, say, 5 miles apart for the scale of the map in use, and by this means, distances may be read off in any direction at the same time as the direction. One of the several types of protractor used for aircraft navigation can be easily adapted.

Whilst bearings with relation to the D.F. station, whether true or magnetic, are always given in degrees, some controls use compass points for bearings with relation to other points of reference on the map.

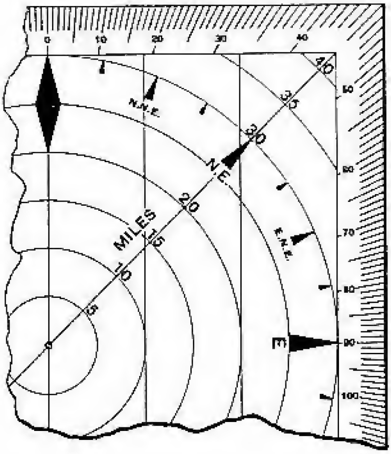

Fig. 435.—A Protractor for Use at a Control D.F. Station.

DETERMINATION OF SENSE

It is a wise procedure, and one that is followed in some of the most important D.F. ground stations, to take a sense reading along with, and preferably before, every bearing, no matter how confident the operator may be as to the location of the transmitting craft. This is a matter that is worthy of special note by the staffs of both shore and mobile D.F. stations.

Sense determination takes only a few seconds and the remainder of the transmission may be used for D.F. If conditions are poor, check bearings may monopolise the whole of the transmitting period, which ceases without sense being known. In the case of a distress call, no further signal may be heard, and there remains complete ambiguity as to the direction of the calling station. If sense be taken first as a routine, situations such as the above are rendered impossible and there becomes less chance of the sense observation being omitted accidentally or due to over-confidence.

As an example of the latter fault, suppose that an aeroplane is approaching an aerodrome ground D.F. station in thick weather and a series of bearings are being given, all of which will have very similar values and the same sense. During an interval between two bearings, the aircraft may pass over the station unobserved, so that, unless sense is noted with the next bearings, reciprocals may be given inadvertently under the impression that the craft is still approaching. This is bound to lead to confusion or danger.

EXPLANATORY NOTES ON " Q " CODE REQUESTS FOR BEARINGS OR POSITIONS

At this point it may be of value to return to the " Q " Code and, selecting some of the various forms of requests for D.F. information, to note the duties devolving upon the control station. In every case it is assumed that the bearings have been corrected for local errors.

Timing of Operations. In the " Answer or Advice " column (page 558) the time is always given when the position of another place or craft is involved in addition to that of the calling aircraft. The time taken to carry out such an operation is usually longer than that required for a simple bearing or position, and the information will be forwarded possibly minutes after the actual request was made. Uncertainty and, possibly, serious inaccuracy would thus be introduced if the time of the measurements were omitted.

True Bearings

The QTE and QGE groups refer to true bearings, the meaning of which has been dealt with on page 259.

QTE *What is my true bearing in relation to you?* This is the reading of the normal or True Bearing scale of the control station D.F., and requires no adjustment.

QTE *What is my true bearing in relation to* X (*Call Sign*) ? This requires cross bearings to find the position P of the calling aircraft, and also a second set of cross bearings to find the position X (the call sign given), if this is another mobile transmitter. P and X having been located on the map at the centres of their respective triangles as shown in Fig. 436, the protractor is centred at X, adjusted parallel to the meridian and the true bearing of P read off.

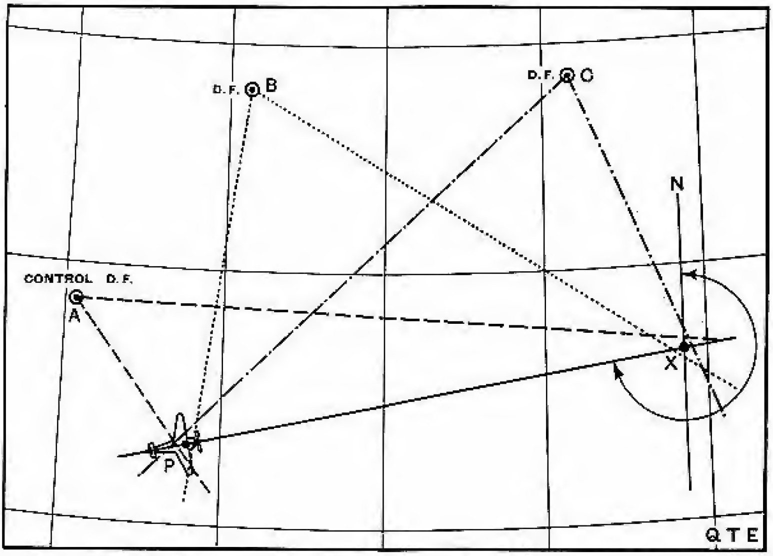

Fig. 436.—**QTE** True Bearing with Relation to the Control D.F. or another Aircraft (or Transmitting Station).

QTE *What is the true bearing of* Y (*Call Sign*) *in relation to* Z (*Call Sign*) ? This is a modification of the above case, in which neither call sign is that of the calling aircraft. The two positions are plotted, the protractor is centred at Z and the true bearing of Y read off.

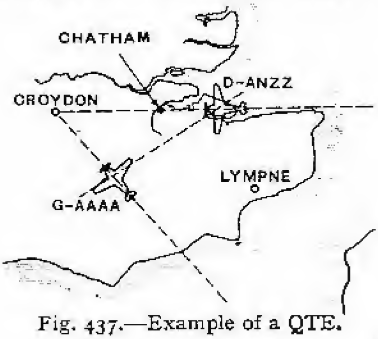

Fig. 437.—Example of a QTE.

Example of Second Form of QTE. As an instance of the use of the second form of QTE, consider the case of, say, an Imperial Airways Paris aircraft G-AAAA, approaching Croydon as in Fig. 437. Suppose that G-AAAA has heard W/T signals from a Luft Hansa aircraft D-ANZZ, strong enough to indicate close proximity. Both aeroplanes are converging on Croydon airport.

A QAI (Has any aircraft been signalled in my neighbourhood ?) would bring an affirmative reply, but the second or third QTE is more informative, as follows :—

GED DE GAAAA QTE DANZZ	Croydon from G-AAAA. What is my true bearing in relation to D-ANZZ ?
GAAAA GED QTE DANZZ 240° 1015	G-AAAA from Croydon. Your true bearing in relation to D-ANZZ was 240° at 1015 G.M.T.

If the position of each aircraft be known and the reply be sent immediately, the time is not signalled. If there is any delay the time is always included.

Both machines may be assumed to be following their usual courses to Croydon and this would be confirmed by the D.F. bearings when obtaining information for their positions.

The above information therefore tells G-AAAA that D-ANZZ is well clear and will not be due until several minutes after his (G-AAAA's) arrival at the airport.

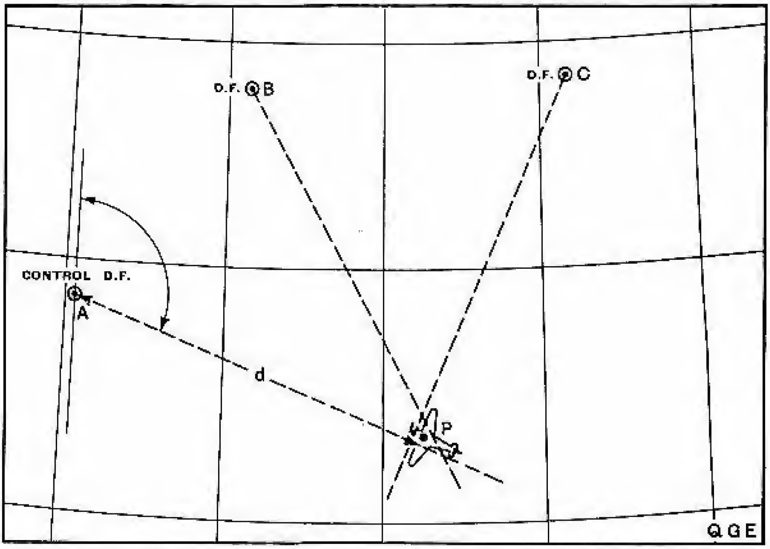

Fig. 438.—**QGE** Position in Terms of True Bearing and Distance from Control D.F. Station.

QGE *What is my position in terms of true bearing and distance from your station?* In this case, the true bearing measured by the control station is usually forwarded immediately. Cross bearings from the other stations then provide the point P, Fig. 438, and the distance of P from the control station is given.

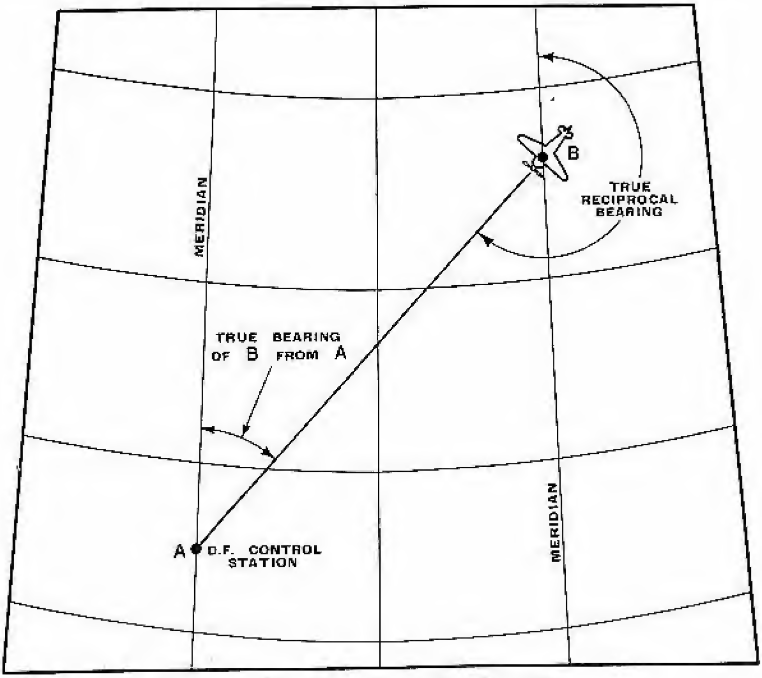

Fig. 439.—The True Reciprocal Bearing.

If the bearing be delayed until the position of P is plotted, and then the true bearing of P from A measured and forwarded, there is little guarantee that this will be any more accurate than the control station's own bearing and it involves a delay of some moments that may be important to the aircraft concerned.

The Reciprocal Bearing. On page 259 it has been seen that the true bearing of B from A is the angle between the meridian through A and the straight line representing the great circle path from B to A as shown in Fig. 439. When the aircraft B, in Fig. 439, is making for an airport A, it will clearly simplify matters for B to know the true course to steer to reach A, and this is the angle shown at B. This angle is the true bearing of A from B, or the **true reciprocal bearing** of B in relation to A, and is a QUJ (below).

Note particularly that, due to convergency, the true reciprocal bearing is not equal to the true bearing +180°, unless A and B are close together.

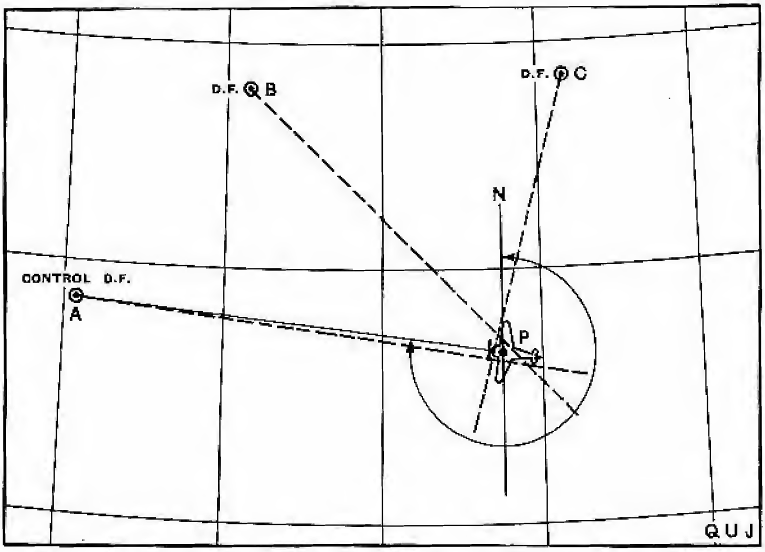

Fig. 440.—**QUJ** True Reciprocal Bearing in Relation to the Control D.F. Station (or some stated place).

QUJ *Will you give me the true course to steer with zero wind to reach you?* The position P is found by cross bearings, the protractor centred at P and the true bearing of A read off as shown, this being the true reciprocal bearing of P in relation to A (Fig. 440).

QUJ *What is the true course to steer with zero wind to reach you or to reach . . . ?* In this case the calling aeroplane does not wish to land at the airport where the control D.F. is situated and gives the name of the desired port. The procedure is then carried out as above, but the reciprocal bearing with respect to the desired port is measured instead of with respect to A.

Position, or Wireless Fix. QTF. *Will you give me the position of my station according to the bearings taken by the direction finding stations which you control?* This is a simple wireless fix, the position being forwarded either as a latitude and longitude or, more commonly, as a bearing and distance from the control D.F. station or from an " Agreed Point of Reference," as in the case of Chatham mentioned below.

A comprehensive list of Agreed Points of Reference is given in " The Air Pilot," which publication should be consulted for much other matter relating to civil aircraft organization.

After fixing P the protractor is centred at the selected point of reference, and preferably one that is ahead of the station requiring its position, and the true bearing in degrees, or the compass bearing, is forwarded together with the distance (Fig. 441).

Example of QTF. For reasons that are mentioned later, requests for positions are comparatively rare, but supposing that the aircraft D-ANZZ, in Fig. 437, desired a wireless fix, the procedure might be carried out as follows :—

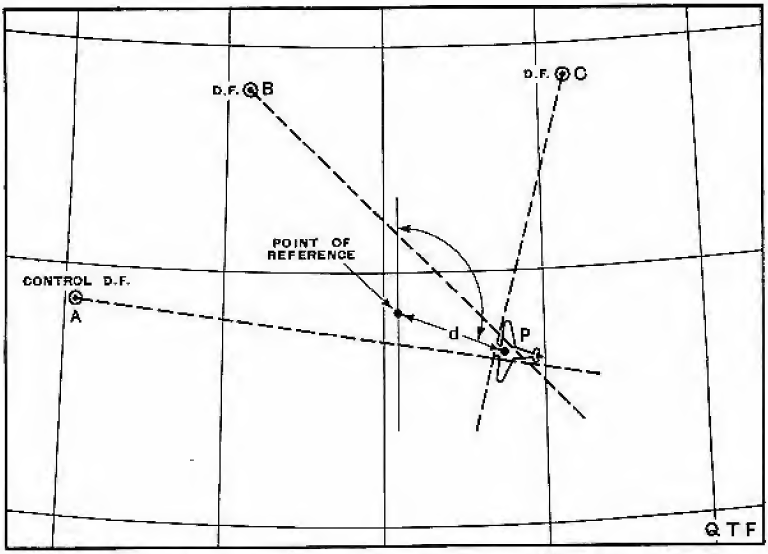

Fig. 441.—**QTF** Position—in Terms that Appear Most Appropriate in the Circumstances.

GED DE DANZZ QTF	To Croydon from D-ANZZ. Will you give me the position . . . etc.
DANZZ DE GED QTG	To D-ANZZ from Croydon. Will you send your call sign . . . etc.
GED DE DANZZ QTG	To Croydon from D-ANZZ. I will . . . etc.

The control D.F. then exchanges bearings with appropriate D.F. stations, obtains a fix and transmits as follows :—

DANZZ DE GED QTF 12 miles E of Chatham (at . . . (time))	To D-ANZZ from Croydon. The position of your station is 12 miles E of Chatham (at . . . (time))

Time is added if delay is appreciable.

GED DE DANZZ (Repeats back position transmitted)	
DANZZ DE GED C AR	To D-ANZZ from Croydon. Agreed .

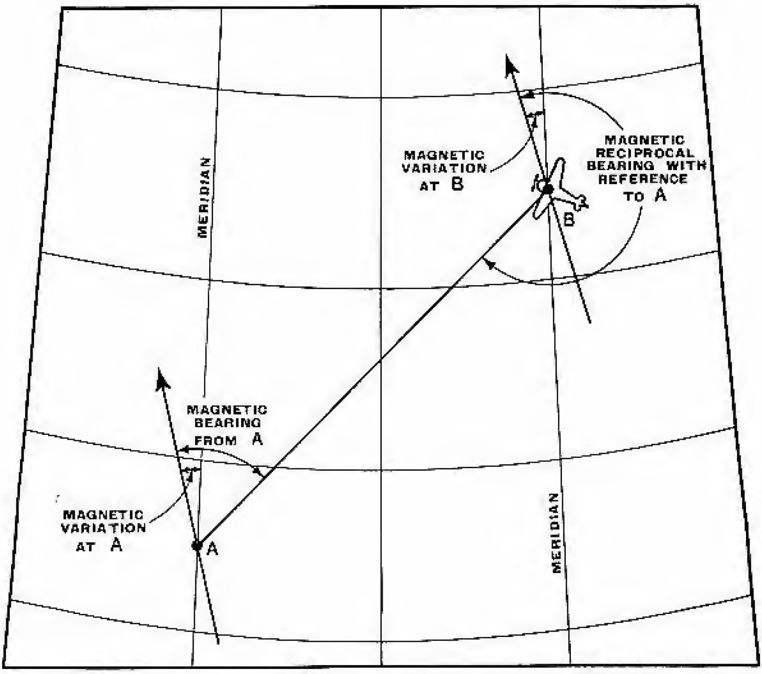

Fig. 442.—The Magnetic Reciprocal Bearing.

Magnetic Bearings

The next three signals refer to bearings, or reciprocal bearings, in relation to Magnetic, instead of true, North. The magnetic bearing of B from A in Fig. 442 is equal to the sum of the True Bearing and Magnetic Variation when the latter is West, as in Great Britain. In places where the Variation is East, the Magnetic Bearing is the True Bearing less the Variation, and 360° must be added if the result is negative. Either case is a QDR.

QDR *What is my magnetic bearing in relation to you?* This is the true bearing of the calling station, from the control stations A, with magnetic variation applied.

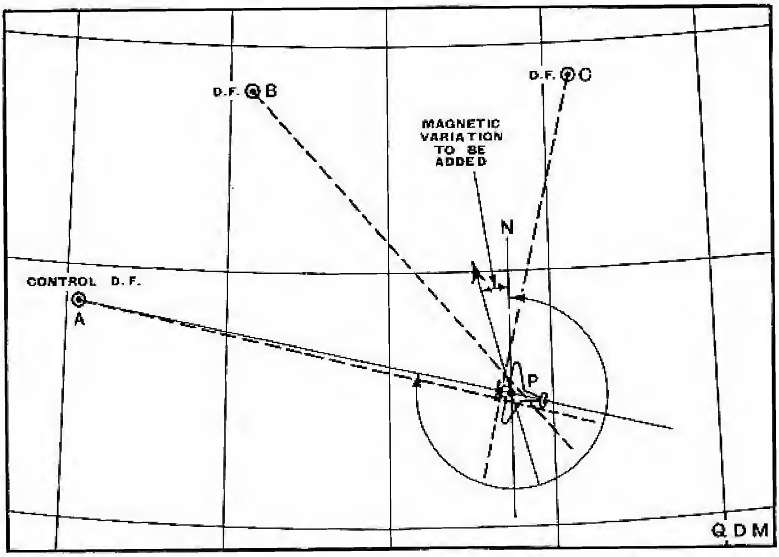

Fig. 443.—QDM Magnetic Reciprocal Bearing in Relation to Control D.F. Station (or some stated place).

Magnetic Reciprocal Bearing. The magnetic bearing is not in great demand, but its reciprocal, the QDM, is extremely popular. The pilot on a regular flying service rarely asks for a QTF. He knows fairly accurately how far he has flown, and his chief concern is to know the direction of his objective so as to avoid waste of time and petrol. A QTF, whilst giving necessary information at times, involves a reference to a map and the measurement therefrom of the bearing of the port and the application of the magnetic variation. A QDM means that the work will be done for him at the control station and all that remains is the correction for drift angle.

QDM *What is the magnetic course to steer with zero wind to reach you (or . . .)?* For the reasons stated in the case of the true reciprocal bearing, it is necessary first to plot the position P of the aeroplane and then to centre the protractor at P, scale off the angle indicated in Fig. 443, and apply the correction for magnetic variation. There is the additional precaution required in this case lest the variation at P should be different from that at A.

For D.F. controls covering a radius of, say, 100 miles in a region where the variation is changing slowly, it will usually be sufficiently accurate to take a mean value for the route concerned, to within the nearest degree.

QGF *Will you give me my position in relation to your station (or to . . .) expressed as the magnetic course to steer with zero wind, and the distance?* The full operation, when the position of P is quite unknown, is first to plot P from the three bearings and then to centre the protractor at P and to read off the magnetic reciprocal bearing as for a QDM, followed by the distance PA. If, from previous communication, P is known to be in the vicinity of A, the convergency and change of magnetic variation will be negligible. In this case, the bearing can be taken as equal to the QDR+180° (that is, the magnetic bearing of P from A+180°) and forwarded immediately, thus saving time, for the reasons mentioned under QGE.

BEARING AND DISTANCE FROM A SINGLE GROUND D.F.

In connection with Fig. 426, it was stated that the position line QR is the only information available from the single D.F. station at A, but the method described below is sometimes used when an aircraft is being guided to an airport and when a fix is essential and no second ground station is available. It is used by Pan American Airways in the case of flying boats approaching port and is illustrated in Fig. 444.

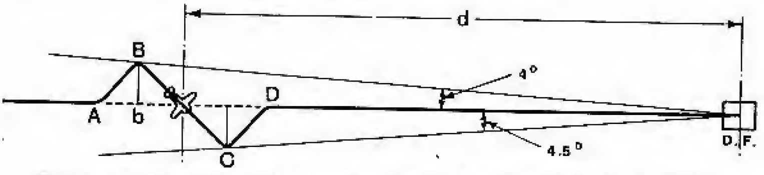

Fig. 444.—Bearing and Distance from a Single Ground D.F. Station.

At a moment agreed upon with the control D.F., a change of course is made of, say, 45° to port, and is flown for such length of time that, allowing for drift, position B is reached where the off-course distance Bb is two miles or some other prearranged amount. This position is signalled to the D.F. and as the aircraft makes a 90° turn to starboard, a bearing is taken from the D.F., the change of bearing being, say, 4°

The aircraft continues on the new course until calculation shows that it must be at C, which is two miles off course on the opposite side and the change of bearing is again noted, say $4\frac{1}{2}^\circ$, after which the normal course is resumed at D as shown or the new course from C is flown.

Taking the mean position of the machine, during the above manœuvre, to be that illustrated in the figure, and knowing that two miles at this point subtends an angle of $4\frac{1}{4}^\circ$ (mean of the two bearings taken), the distance from the D.F. is easily found from the following expression :—

$$\frac{2 \text{ miles}}{\text{d}} = \tan 4\tfrac{1}{4}^\circ$$

so that d = 27 miles.

If the ground D.F. is not equipped with an Adcock aerial, precautions must be taken as to the aerial for transmitting from the aeroplane, a trailing aerial being unsuitable unless a course towards the D.F. is maintained whilst the bearing is being taken. (Aeroplane effect, page 192). The method is obviously unsuitable for use at very short or very great distances, as in the latter case the off-course flight necessary to get a measurable bearing and reasonably accurate result, would be excessive.

COASTAL D.F. SERVICE

The procedure to be followed when requesting bearings from coastal D.F. stations is covered by Appendix 13 to Article 30 of the General Radiocommunication Regulations that are given on page 547. Particulars of the comprehensive list of all D.F. stations were also mentioned. The necessary information regarding coastal D.F. stations also appears in The Admiralty List of Wireless Signals as well as in the publications of many other countries.

W/T Direction Finding Stations (which Transmit Bearings on Request). In Vol. 1 of " The Admiralty List of Wireless Signals," 1937, under the above heading, there is a list of about 130 D.F. stations that are available for shipping, some examples of which are reproduced overleaf.* Note that the German stations form an associated group, of which Nordholz is the control station.

The latitudes and longitudes in heavy type refer to the transmitting stations and are for use in plotting bearings taken by a D.F. installed in the ship. The mark (†), beside the Land's End station quoted, for instance, signifies that the transmitter associated with this station will send QTG signals on request.

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* By kind permission of The Controller of H.M. Stationery Office. See important notice on page 546.

1008 †**Land's End D.F. (GLD).** 50° 07′ 04″N. 5° 40′ 05″ W.
WAVE: 375 kc/s (800 m.). TYPE: A2, B. POWER: 5·0 kW.
SECTORS: Calibrated: 000°—360°.
Unreliable: 027½°—155½°, 202½°—231°. (Will be stated as such when given; further investigations proceeding.)
CALL FREQUENCY: (a) 2300—0800: 500 kc/s; results transmitted on same frequency. TYPE: A1, or A2.
(b) 0800—2300: 375 kc/s; results transmitted on 385 kc/s. TYPE: A2.

(North Sea, German D.F. Group: *See* Nos. 1057, 1065, 1065A and 1074).

1057 **Borkum D.F. (DBM).** 53° 36′ 10″ N. 6° 41′ 18″ E.
53° 34′ 48″ N. 6° 40′ 12″ E.
WAVE: 375 kc/s (800 m.). TYPE: A2.
SECTOR: Calibrated: 000°—360°.

1065 **Nordholz D.F. (DBZ).** 53° 47′ 06″ N. 8° 38′ 18″ E.
WAVE: 375 kc/s (800 m.). TYPE: A2. POWER: 250 m.-a.
SECTOR: Calibrated: 000°—360°.

1065A **Nordholz (DBN)** (CONTROL STATION). 53° 46′ 45″ N. 8° 38′ 21″ E.
WAVE: 375 kc/s (800 m.). TYPE: A2.

1074 **List D.F. (DBT).** 55° 01′ 29″ N. 8° 26′ 22″ E.
55° 01′ 23″ N. 8° 26′ 36″ E.
WAVE: 375 kc/s (800 m.). TYPE: A2.
SECTOR: Calibrated: 000°—360°.

Coastal D.F. Organization. By comparison with a busy airport control D.F. station, the coastal D.F. station procedure is more stereotyped and also, at the present day, more leisurely. A number of the code groups, as, for instance, QTE, QTF and QTM were originated for shipping and are still in use. Regarding the organization of the work, there is little to add to what has already been said concerning the aircraft ground station and since the great majority of coastal D.F. stations are not associated with a group, their work is confined to the supply of true bearings only.

PRACTICAL EXAMPLES OF THE USE OF GNOMONIC AND MERCATOR'S CHARTS IN THE CALIBRATION OF A D.F. STATION

A common use of the gnomonic graticule is in taking check bearings during the calibration of a shore station. The bearings are required to be known with as much accuracy as possible and yet, owing to the large number of transmitting stations within range—any of which may or may not be transmitting when required—it would be a tedious task to calculate all the great circle bearings. This is particularly the case when the D.F. station is a temporary one.

In Chapter 9, when dealing with the coastal D.F. installation, it is mentioned that whenever possible a ship should be detailed to cruise within optical range of the station for calibration purposes. This cannot be relied upon in every instance, however, and in any case check bearings are advisable on transmitters at much greater distances than the optical range. Similarly during the process of choosing the site, or after completion of the Aircraft Ground D.F. installation, bearings on all transmitters on the working wave lengths are desirable in addition to the more essential calibration by bearings on aircraft in flight.

Suppose that it had been decided to erect a D.F. station in the neighbourhood of the Hook of Holland for the purpose of aiding the navigation of ships or aircraft crossing the North Sea. A suitable site having been chosen, the position of which is, say, lat. 52° N., long. 4° 08′ E., the station is erected and the apparatus installed, and it is then desired to take check bearings on transmitting stations in as many directions as possible for the purpose of calibrating the station.

For ship work, the D.F. should be calibrated principally on the 800 m. wave and also on the emergency 600 m. wave. For aircraft, the wave length is 900 m., and a glance at a wireless map of Europe will show that although there is a very large number of 600 m. transmitting stations available for checking purposes within range of a D.F. station in Holland, for the remaining waves few transmitters are available, and the alternative is to do the best possible with the long-wave broadcast transmitters.

Choice of Gnomonic Chart (Graticule). Bearing in mind that the latitude of the D.F. station should correspond as closely as possible to that of the point of contact of the chart, we see that chart F of the 25 miles to the inch series (page 263) will meet the case. This chart, which extends from lat. 47° 30′ to 62° 30′ N., includes about 26 degrees of longitude and has its point of contact in latitude 55° N. which is within 3° of the D.F. station site.

Locating the D.F. and Transmitting Stations on the Chart. The charts as supplied have the parallels of latitude numbered off, but the meridians are left blank in order that the one passing through the point of contact may be given the value nearest to that of the D.F. station. In this case the longitude of the D.F. is 4° 08′ E. and so the centre meridian of the chart is called 4° E. and the remainder numbered off accordingly, as shown in Fig. 445. (The charts when used in the northern hemisphere should have the parallels of latitude concave upwards.)

Having numbered off the meridians, the positions of the D.F. station and transmitting stations in range are plotted, each station being marked by a dot with a small circle round it and the call sign marked alongside. Lines are next drawn through the D.F. station and each transmitting station in turn, and a line is also drawn through the D.F. station parallel to the nearest meridian on the chart, to represent the direction of North. The bearings of the transmitting stations can now be scaled off with a protractor.

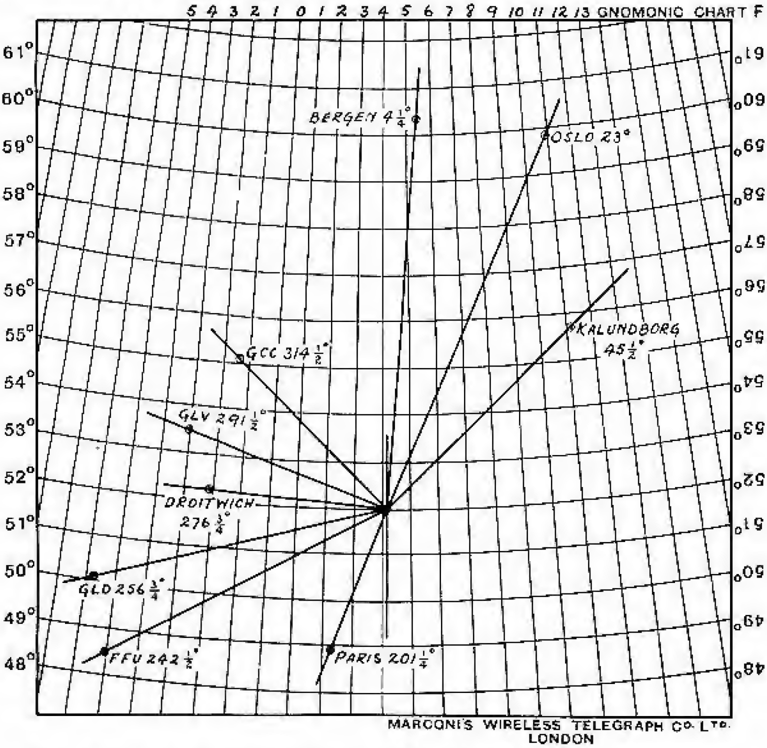

Fig. 445.—Use of Gnomonic Graticule to obtain True Bearings of Transmitting Stations from a D.F. Station.

The Use of the Mercator's Chart in the Above Example. The limitations of the Mercator's chart for D.F. work have already been discussed on page 270, but occasions may arise when use has to be made of such a chart in order to find the great circle bearings of transmitting stations for calibrating purposes. For distances between the D.F. and transmitting stations greater than 1,200 miles it is preferable to calculate the bearing in every case if accuracy is desired, but for shorter distances than this, the Mercator's chart may be used and correction for half-convergency applied to the bearings so obtained.

Fig. 446 shows a sketch map of England and Holland on the Mercator's projection, and we will suppose that it is desired to find what the bearing of Seaforth W/T station (GLV) ought

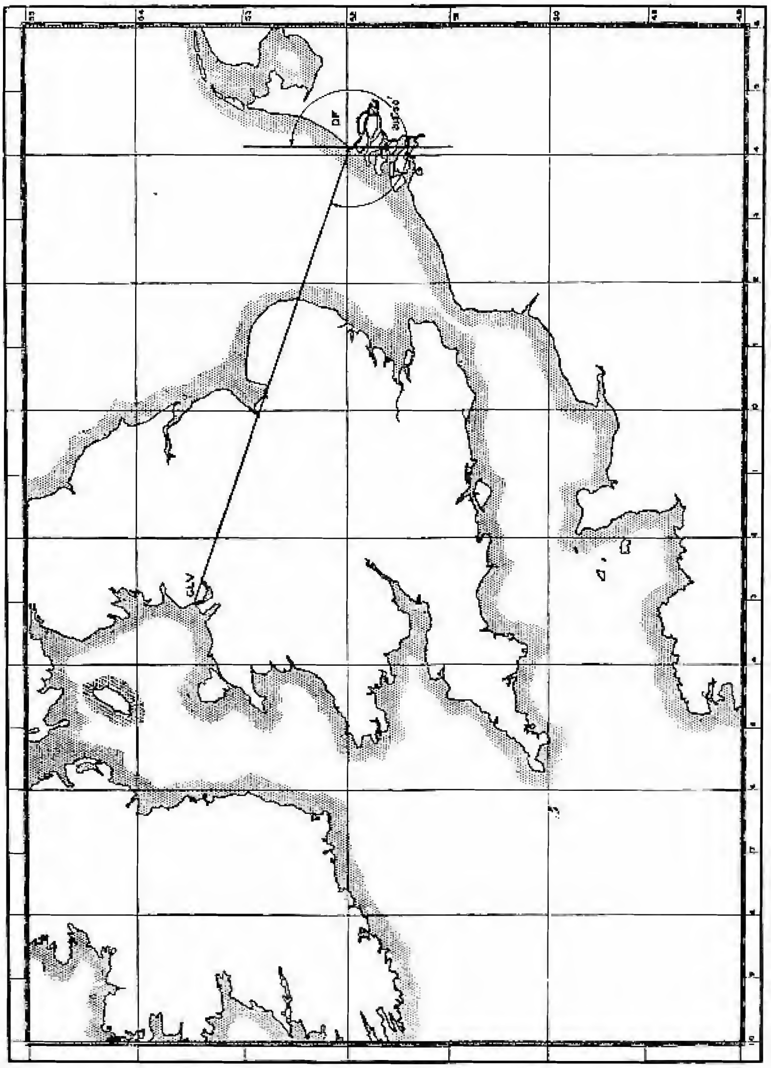

Fig. 446.—Use of Mercator's Chart in Obtaining the True Bearing of a Transmitting Station from a D.F. Station. (*Based upon British Admiralty Chart with the permission of the Controller of H.M. Stationery Office and of the Hydrographer of the Navy.*)

to be at the D.F. station in Holland, previously mentioned. The position of GLV is given as lat. 53° 28′ 14″ N., long. 3° 00′ 42″ W., and having fixed this point and that of the D.F. station, a line is drawn between the two with a straight-edge. The rhumb line bearing of GLV at the D.F. is then measured with a protractor and found to be 288° 50′, to which must be applied the half-convergency.

$$\text{Diff. long.} = 3^\circ\ 01' + 4^\circ\ 08' = 7^\circ\ 09'$$

$$\text{Mid. lat.} = \frac{53^\circ\ 28' + 52^\circ}{2} = \frac{105^\circ\ 28'}{2} = 52^\circ\ 44'$$

and from the H.-C. diagram, of Fig. 242, the half-convergency = 2° 50′.

Since the mid. lat. is north and the distant station is west of the D.F., the correction must be *added*, so that the great circle bearing of Seaforth is 288° 50′ + 2° 50′ = 291° 40′.

Discrepancies in Calculated and Measured Bearings. The bearings as found by either of the above chart methods do not differ from the calculated bearings by more than a small amount, which usually is well within the limits of experimental error and may be neglected. Thus, comparing the nine values obtained from the gnomonic chart in Fig. 445 with the calculated values, the maximum error is found to be only a third of a degree, whilst the mean error is less than a quarter of a degree. Again the corrected Mercatorial bearing of Seaforth, which was found above to be 291° 40′ differs from the calculated bearing (291° 35′) by five minutes only, which is negligible.

POSITION FINDING BY D.F. INSTALLED IN SHIP OR AIRCRAFT

We come now to the far more flexible method of navigation, namely, by the mobile D.F., in which case a position line can be obtained through any transmitting station within range, if the precautions mentioned on page 598 are observed. Two or more wireless position lines can be combined to give a fix, or the wireless position line may be combined with those obtained by astronomical or other means some of which are mentioned later.

The setting of the course of the ship or aircraft in accordance with the information obtained by these fixes involves allowances for wind, tide, currents and a multiplicity of other factors that are beyond the scope of this chapter, the object of which is to inform the " wireless " reader the purpose of, and the demands likely to be made upon, D.F. apparatus.

The more restricted homing methods of using transmitters for navigating have been dealt with in Chapter 13, and there the effects of drift were mentioned. This was clearly necessary to the understanding of aircraft homing, which is not only an essentially wireless method of reaching an objective, but is also a progressive process in the intermediate stages of which the actual position of the craft may never be known. This section deals, on the contrary, with wireless methods of fixing a position, from which a course may be set.

Some examples are given on page 603 of methods of plotting wireless fixes, but for further information on the art of navigation in the true sense, reference must be made to text-books on the subject. "Air Navigation," British Empire Edition (McGraw Hill), by Commander P. V. H. Weems, may be recommended in this connection and many books on marine navigation are available.

Relative and True Bearings. In the case of the shore D.F. it was seen to be almost universal practice to arrange the scale and pointer in such a way that bearings of stations are read off as angles east of true North ; a station due north of the D.F. being indicated at 0° on the scale of the instrument. On ship-board this is no longer possible since normally the scale is fixed relatively to the ship, which may be sailing on any course. It is standard practice, under these conditions, to calibrate the instrument so that 0° on the scale indicates the direction of a station dead ahead of the ship. Bearings are hence read off clockwise from this direction and are known as **Relative Bearings.**

In order to obtain the true bearing of a distant station it is necessary, in addition to the D.F. bearing, to know also the course of the ship at the instant the bearing was taken and considerable skill and experience are necessary for the accurate simultaneous reading of these two bearings in a ship at sea.

The gyro compass repeater in the ship and the directional gyro (page 620) in aircraft are great aids in this respect.

The above situation is illustrated in Fig. 447, where X is a ship fitted with D.F. and sailing on a course XY. A bearing by D.F. of a transmitting station P is found to be 40°, *i.e.*, 40° on the starboard bow, which, in itself, is of no particular value for the purposes of navigation, since there is not enough information to lay off a position line through P. If, however, at the instant of taking the D.F. bearing, a reading had been taken of the magnetic compass and found—after being corrected for magnetic variation and deviation and converted to degrees (page 741)—to give the ship's course as 30° east of North, then the true bearing of the station P from X would have been 30° + 40° = 70° east of North.

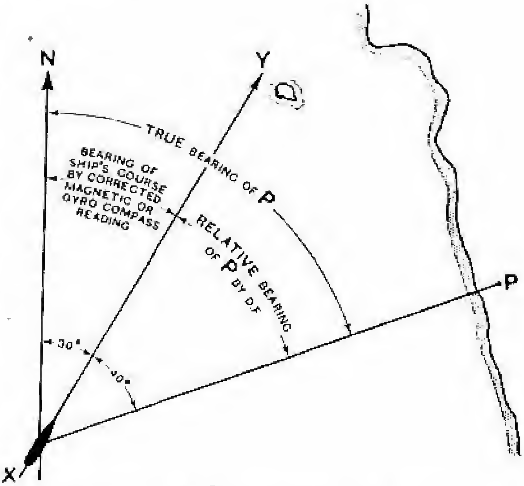
N
Y
TRUE BEARING OF P
BEARING OF SHIP'S COURSE BY CORRECTED MAGNETIC OR GYRO COMPASS READING
RELATIVE BEARING OF P BY D.F.
P
30°
40°
X

Fig. 447.—Relative and True Bearings.

In ships fitted with a gyro-compass, and having a repeater in the wireless cabin, it is only necessary to note the reading of the compass and the D.F., to add them together, subtract 360° if necessary and the result is the true bearing since the gyro-compass has no variation or deviation.

If a True Bearing Indicator (page 444) be fitted, or better still, if the gyro-compass controls the scale of the direction finder, true bearings can be read direct. Provision is made for this in the Radiomarine

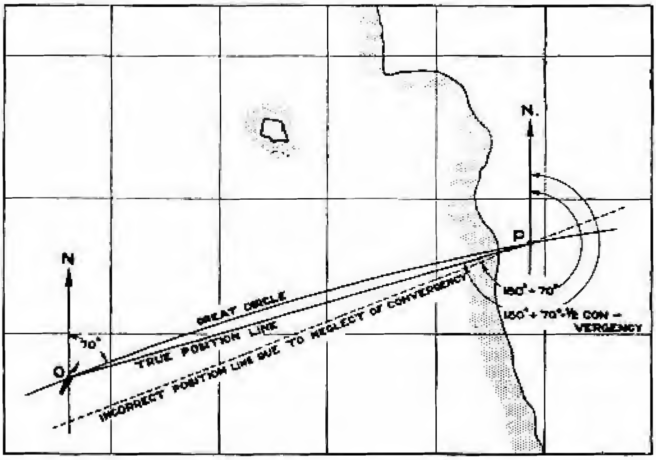
N.
N
P
O
70°
GREAT CIRCLE
TRUE POSITION LINE
INCORRECT POSITION LINE DUE TO NEGLECT OF CONVERGENCY
180° + 70°
180° + 70° + ½ CON-VERGENCY

Fig. 448.—Position Line on Mercator's Chart from True Bearing of One Transmitting Station.

Corporation of America and the Federal Telegraph Company direction finders described in Chapter II.

Provided that the transmitting station is known to be not more than about 100 miles distant from the ship in Fig. 447, the 70° true bearing of P is sufficient to enable a position line to be laid off forthwith on an ordinary nautical chart through the point P.

For long distance work, the discrepancy between rhumb line and great circle bearings introduces still greater difficulties than in the case of shore station working, and if a situation arises in which the distance of the station on which the bearing has been taken is not even approximately known, the only methods of obtaining a position line are by means of :

(1) Mercator's chart provided with lines of bearing. (Page 272.)

(2) Retro-zenithal chart. (Page 264.)

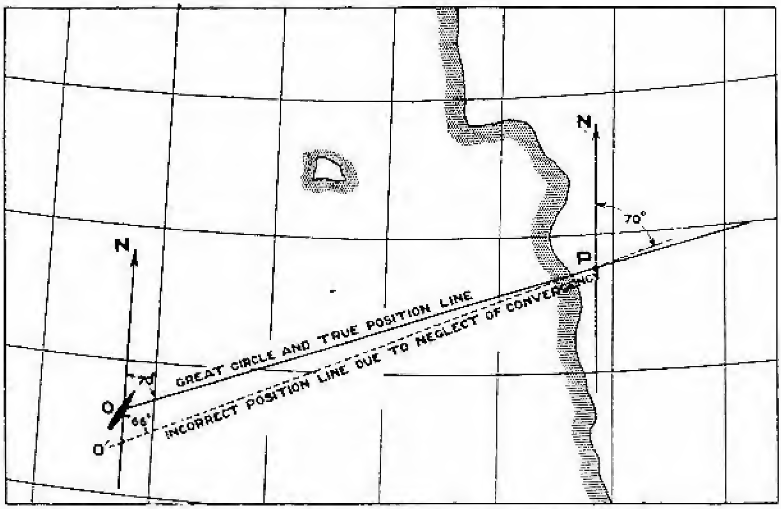
N
N
70°
P
GREAT CIRCLE AND TRUE POSITION LINE
INCORRECT POSITION LINE DUE TO NEGLECT OF CONVERGENCY
70°
O
66°
O'

Fig. 449.—Position Line on Gnomonic Chart from True Bearing of one Transmitting Station.

Neither of these charts is commonly to be found in a ship and they will not be considered further. In any case the position line would not be a reliable one, since the magnetic variation would not be known and the value chosen might be some degrees in error.

Position Line from Bearing of One Station. The situation mentioned above is unlikely to be met with in practice, as, even if the ship has been unable to take astronomical bearings for some time, there will be an "estimated position" from dead-reckoning, known as the D.R. position. This will give the approximate magnetic variation and also enable the correction for convergency to be applied as described in Chapter 8, and a position line to be laid off *from* the transmitting station on a nautical chart.

The estimated position of the ship will also give the approximate meridian, and thus enable a position line to be plotted on a gnomonic chart *from* the meridian of the ship *to* the station, thus avoiding the convergency error.

These operations are illustrated in Fig. 448 and Fig. 449, to which further reference will be made when considering cross-bearings from more than one station.

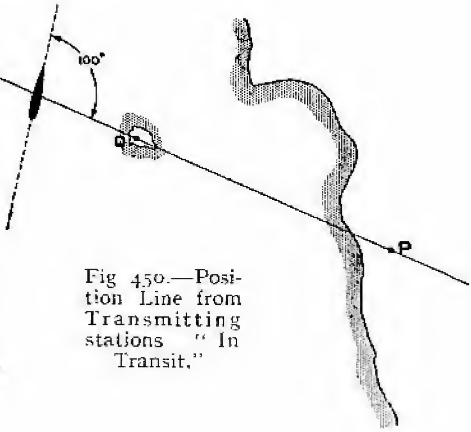

Fig 450.—Position Line from Transmitting stations "In Transit."

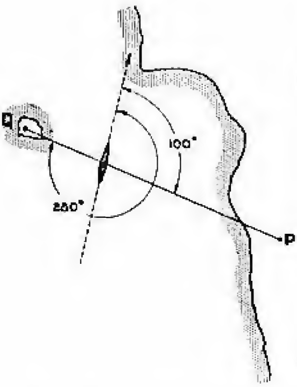

Fig. 451.—Alternative Case of Position Line from Transmitting Stations "In Transit."

Position Line from Bearings of Stations "In Transit." When a ship finds herself exactly in line with two transmitting stations, whether she be between the two stations or on an extension of the line joining them, the stations are said, as far as the ship is concerned, to be "in transit." This gives a position line immediately, as will be seen from the examples in Fig. 450 and Fig. 451. In the first case, the ship, having taken the true bearings of the stations P and Q, finds that each of them bears 100°, and knowing the positions of the stations, the position line PQR is at once obtained. Similarly in Fig. 451 the bearing of P is found to be 100° and that of Q, 280°; that is to say, the signals arrive 180°

apart on the scale of the D.F., indicating that the ship is on the line joining them.

On the nautical chart these position lines suffer from the same limitations as others and cannot be laid off accurately when the distances involved are much greater than 100 miles, but since on the gnomonic chart all great circles are always straight lines, the position lines may be drawn to the limits of the chart. It is only the zenithal properties that depend to some extent upon the relative positions of the stations and the point of contact.

Fix by Cross Bearings of Two Stations. We have seen that unless the position of a ship is approximately known it is impossible to lay off an accurate position line by means of a single bearing on a transmitting station, except in certain circumstances. If a second or "cross bearing" can be obtained, both position lines can be drawn and the position of the ship thereby fixed.

In Fig. 452, suppose that a ship takes bearings of the stations Q and P and finds them (after correcting) to be 30° and 80° respectively. Then, knowing the positions of Q and P, it is required to reconstruct the state of affairs on a chart, not knowing the estimated position of the ship.

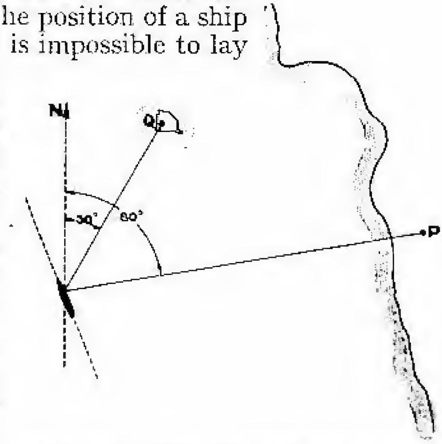

Fig. 452.—Fix by Cross Bearings, from Ship D.F., on Two Transmitting Stations.

Cross Bearings on Mercator's Chart. Suppose Fig. 453 to represent the above conditions on a nautical chart. The position of the ship is not known, but the true bearings, at a certain time, of the stations Q and P were 30° and 80° respectively, corrections having been made for magnetic variation and deviation, the former being only an approximate figure. Now it is impossible to get a fix by laying off the reciprocals of these bearings *from* Q and P since, although the bearing of Q from the ship is 30°, the bearing of the ship from Q is not 180° + 30° = 210°, but some other angle, depending on the relative disposition of the ship and the station Q.

If the approximate position were known, then the correction could be applied to the bearing, which would enable it to be laid off, and this indicates the method to be employed to obtain a fix. Lay off the bearings *from* the stations Q and P, as shown by the dotted lines in Fig. 453, and the intersection will give an approximate position for the ship at O. From this a check can be obtained on the value taken for the magnetic variation, which may affect the figure taken for the true bearing. It will also give the difference of longitude between the ship and Q, and the middle latitude between the places, enabling the convergency correction to be worked out from the expression :

$$\tfrac{1}{2}\text{ convergency} = \tfrac{1}{2}\text{ diff. long.} \times \sin\text{ mid. lat.}$$

Having made these adjustments to the original bearings, they can again be laid off from Q and P and a closer approximation to the true position will now be obtained at O′.

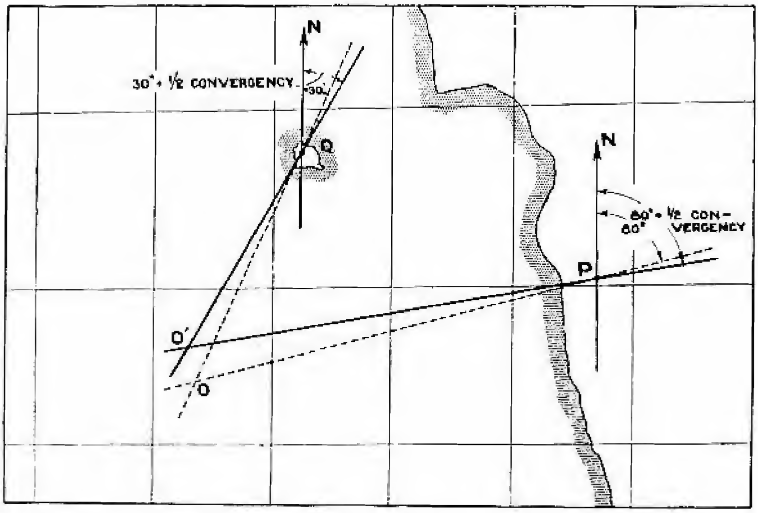

Fig. 453.—Plotting Fix by Cross Bearings, on Mercator's Chart.

The Station Pointer. Instead of laying off the bearings on the chart in order to find the approximate position of the ship, a station pointer may be employed for the purpose and will give the same result, namely, at O. The corrections are then made to the bearings, the arms of the instrument adjusted accordingly, and the second fix O′ obtained.

Cross Bearings on the Gnomonic Chart. The disadvantage of using the nautical chart is thus the necessity of making a small calculation in connection with almost every long-range bearing before it can be applied to get a fix, and Fig. 454 shows an attempt to lay off the position lines on a gnomonic chart, the position of the ship being unknown, as before. If a graticule be used, it will be assumed that a suitable one has been chosen for the latitude of Q and P. Since the degree of accuracy of a shore station cannot be obtained in a ship, there is no great need to ensure that the estimated position of the ship should come very close to the point of contact of the chart.

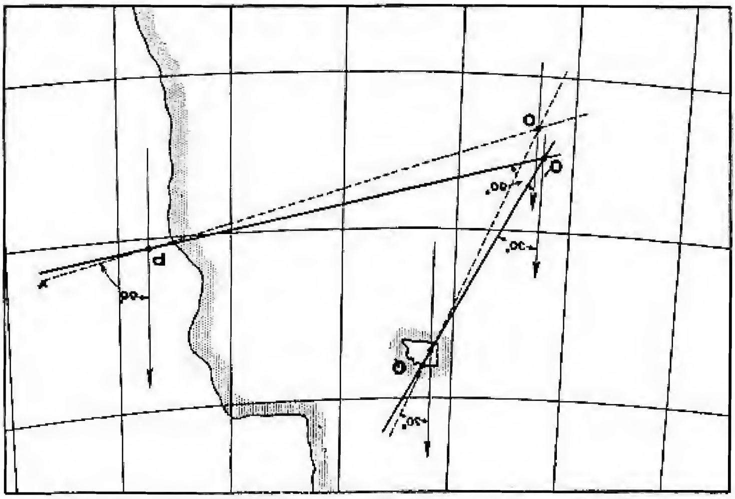

Fig. 454.—Plotting Fix by Cross Bearings, on Gnomonic Chart.

As before, lay off *from* Q and P the bearings obtained from the ship. These will not be the true position lines, but will intersect at some point O and give an approximate position for the ship. This rough fix will give a check on the figure for the magnetic variation which was used to obtain the bearings, and they can be corrected in accordance with this if necessary. In addition to this, the meridian of the point O can be assumed to be the meridian of the ship when the bearings were taken, and the position lines may now be laid off *from* this meridian, through the respective stations, and a new point of intersection obtained.

Dead Reckoning Position. If the D.R. position may be taken as being approximately correct, the above processes are simplified, for it is no longer necessary to find the first point O, bearings being laid off from the meridian through the D.R. position.

A simple method of laying off a position line from a D.R. or approximate position O is shown in Fig. 455. Assuming that the true bearing of the transmitter P is 70°, a line is first drawn through O making 70° with the meridian and then, using parallel rulers, a second line parallel to the first is drawn through P, giving the required position line.

The Station Pointer. When using a gnomonic chart, the use of a station pointer will be found to simplify the plotting of a fix considerably. As before, the arms of the instrument are set to include respectively the true bearings of the stations P and Q from the ship. Since the gnomonic chart reproduces great circles as straight lines, and the great circle angles are correctly rendered, the state of affairs which existed at the instant the bearings were taken is reconstructed with a minimum expenditure of time and trouble. A pencil mark is made at the centre of the station pointer giving the fix.

On page 603 will be found examples on the practical use of charts in navigation by cross bearings, using both nautical and gnomonic charts.

Fix by Cross Bearings of Three Stations. The remarks at the beginning of the chapter regarding the accuracy obtainable in wireless direction finding by means of shore stations (Fig. 429 and Fig. 430), apply with equal force when the D.F. is installed in a ship, and a cross bearing on a third shore station

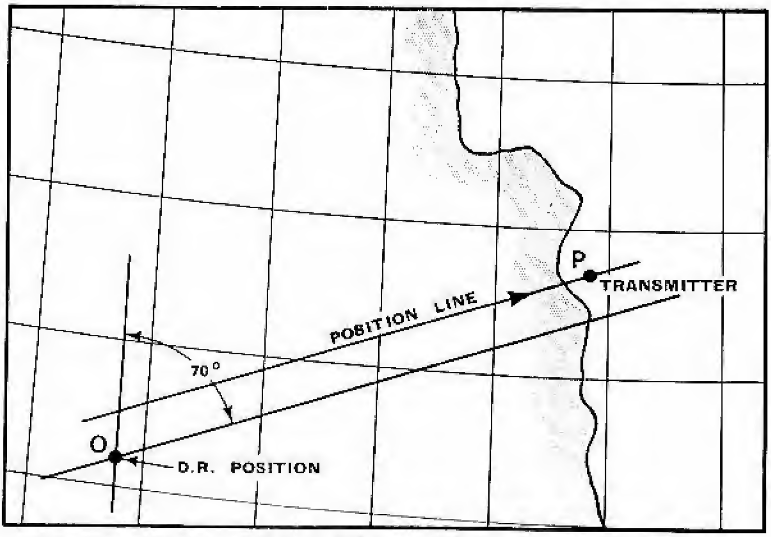

Fig. 455. Bearing of P Laid Off from D.R. Position and Transferred to Pass Through P.

will materially improve the value of the fix. A "cocked hat" will frequently be produced by the intersection of the lines, owing to errors which have been detailed on page 563, and the last one mentioned, namely, that due to the time which elapses between the taking of the first and last bearing, is more often met with in aircraft navigation, owing to the high speed of the aeroplane. The following is a method whereby allowance can be made for the distance travelled in the interval between taking two bearings.

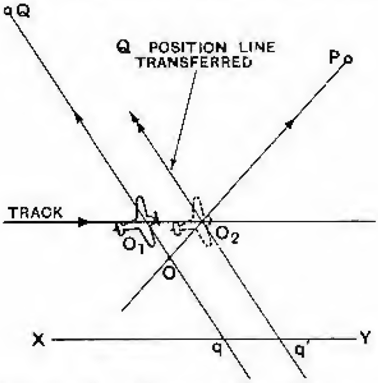

Fig. 456.—Allowance for Distance Travelled in Interval Between Bearings.

Allowance for Distance Moved by Aircraft Between Cross Bearings. In Fig. 456, suppose that the bearing of Q was obtained 3 minutes before that of P, during which time the track of the aircraft was due East, the ground speed being 180 m.p.h. The distance moved in the interval would thus be 9 miles and the point O would not represent the position of the machine at any time during the period.

Draw any line XY in a direction parallel to the track of the aircraft, intersecting the Q position line at q. Mark off from q a distance of 9 miles in the direction of travel, giving the point q′, and through q′ draw a line parallel to the Q position line, giving the "Q position line transferred."

At the time of taking the second bearing the aircraft must have been somewhere on this Q position line transferred, and it was also on the P position line, so that the intersection O_2 gives the second position of the machine and the track may be drawn as indicated. O_1 was the position when the Q bearing was taken.

In plotting the direction of a ship's course, in a similar case, due allowance must always be made for wind, tide and currents and the compass reading alone must not be taken to represent the course.

Position Circle. Angle Subtended at Ship by Two Shore Stations. Suppose that the ship O in Fig. 457, instead of taking true bearings of P and Q, measures only the angle subtended by the stations, that is to say, the angle POQ.

Instead of fixing the position of the ship, this gives a **position circle** as shown. Students of Euclid will recognise the conditions as those of a proposition which proves that in the arc AOB of any circle AOBC, as in Fig. 458, all the angles AOB, AO′B, AO″B, etc., are equal to one another. Similarly, all the angles on the other side of the chord AB, such as ACB, AC′B, etc., will be equal to one another, but will not be equal to AOB unless AB be a diameter of the circle.

If, therefore, in Fig. 457, the angle subtended by P and Q be found to be 60°, then the ship must lie somewhere on the arc POQ of a circle of such a diameter that all angles POQ, PO′Q, etc., are equal to 60°.

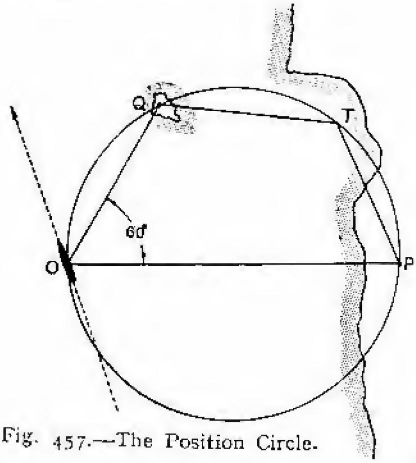

Fig. 457.—The Position Circle.

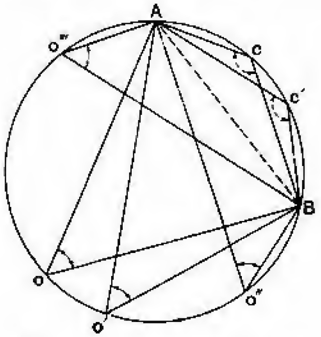

Fig. 458.—Geometry of the Position Circle.

A simple geometrical construction will provide the centre of this circle if it is required.

Intersecting Position Circles. Angles Subtended at Ship by Three Shore Stations. If, as in Fig. 459, a third station be available and the angle QOR be measured by the D.F. to be 100°, then a second position circle can be drawn for the stations Q and R. Now the position of the ship must lie on both these circles, and therefore, as in the case of position lines, it will be at the intersection O, the other intersection being the common station Q.

In the case of bearings on three stations, the station pointer is particularly useful, and it was, indeed, in connection with the "horizontal sextant angles" of ordinary navigation that the instrument was first developed. This type of fix, being quite independent of the magnetic compass, is about the most rapid and accurate one which can be got, but the accuracy largely depends upon the relative disposition of the stations and the ship, and the fix becomes unreliable when the position of the ship is anywhere near the circumference of the circle drawn through the three stations. This point is discussed below.

Special Case when Position Circles Coincide. If the ship O in Fig. 460 is in such a position that the two position circles PQO and RQO coincide, then it will not be possible to obtain a fix from observations of subtended angles alone. For instance, suppose that at a certain time the angles POQ and POR are found to be 25° and 128° respectively, and that an attempt be made to fix the ship's position by means of a station pointer, it will be found impossible to do so, since

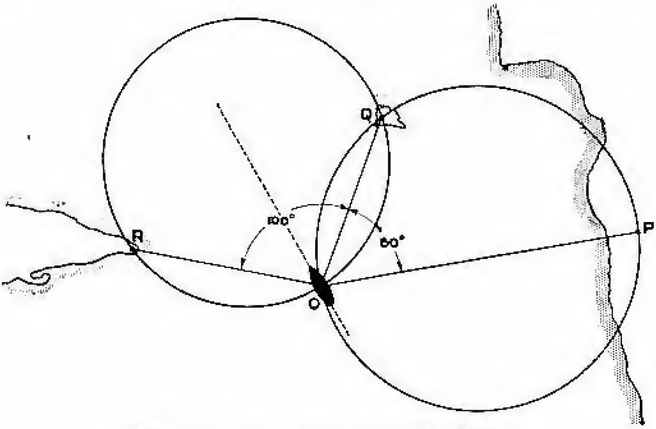

Fig. 459.—Intersecting Position Circles.

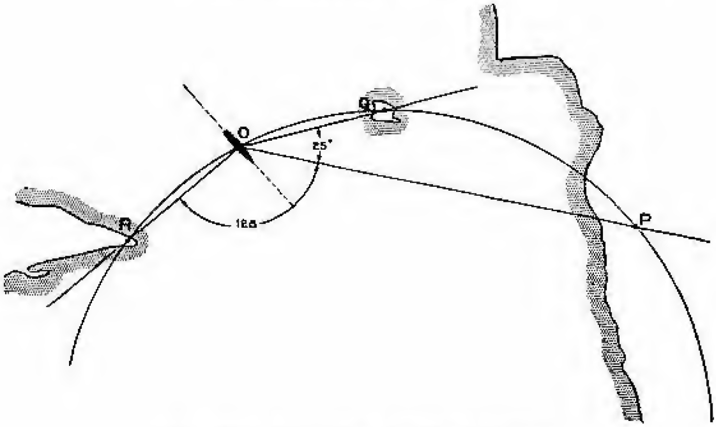

Fig. 460.—Coincident Position Circles.

the conditions are satisfied at any point of the arc ROQ for reasons already stated. In such a case, the only methods of getting a wireless fix are either by taking the true bearings of one or more of the stations and plotting position lines to intersect this circle, or by waiting until the ship has proceeded on her course and the position circles are no longer coincident.

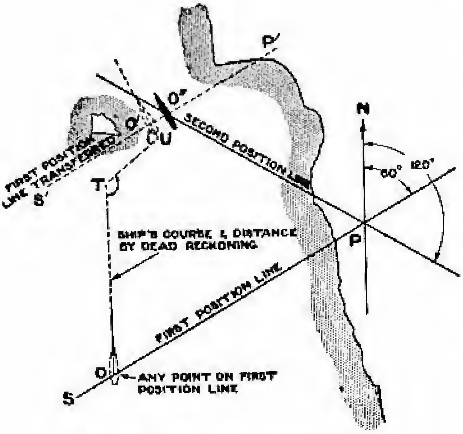
P′
O″
O′
U
SECOND POSITION LINE
FIRST POSITION LINE TRANSFERRED
S′
T
N
60°
120°
P
SHIP'S COURSE & DISTANCE BY DEAD RECKONING
FIRST POSITION LINE
O
ANY POINT ON FIRST POSITION LINE
S

Fig. 461.—The Running Fix.

Running Fix by Bearings on a Single Station. This is a method of fixing the position of the ship from bearings on a single station and is of particular use when coasting. Suppose that in Fig. 461 the ship takes a bearing of the shore station P and finds it to be 60°. This position line is laid off on the chart from P in the direction PS and is called the " First Position Line." This is essentially a case for the employment of the nautical chart, since the method is almost useless at great distances from the transmitting station, owing to the time taken to obtain a result. At the instant of taking the first bearing, the patent log is read and a record is kept of the course of the ship and the distance run on each course if the course be changed. As soon as the bearing of P has appreciably altered (the change should be at least 30°, and is shown as 60° in Fig. 461), another bearing is taken, and the patent log again noted. The method of fixing the position of the ship is then as follows :

It is known that when the first bearing was taken the ship was somewhere on the line P S. Choose any point O and let this be supposed to be the position. Now, from O lay off the courses and distances of the ship up to the time of taking the second bearing, and suppose these to be represented in the figure by the line OTUO′. Through the point O′, draw the " First Position Line Transferred," P′O′S′. (See page 591 with reference to Fig. 456.)

If, now, the second bearing, which we will assume was 120°, be laid off from P, it will cut the line P′O′S′ at some point O″, which was the ship's position at the instant of taking the second bearing.

Running Fix by Bearings on Ship Transmitter. In Fig. 462 P_1 and P_2 are two positions of a ship on a steady course and O is an aircraft on an ocean flight. The aircraft navigator obtains the true position of P_1 by W/T at a given time and takes a bearing of the ship which he notes as, say, 88° magnetic. The speed and course of the ship having been ascertained, the position P_2, 30 minutes later, can be found and at that time a second bearing is taken from the aircraft, namely, 147° magnetic.

If the speed of the aircraft over the sea is 180 m.p.h. the first position line P_1 S must be transferred a distance of 90 miles in the direction of the aircraft's actual track, allowing for drift, to S′P′ as shown. The position of the aircraft when the second bearing was taken must now be on this line S′P′ and also such that the 147° magnetic bearing passes through P_2. The reciprocal is shown as being laid off from P_2 on the assumption that convergency error is negligible and this fixes the second position at O″ and the correct track as shown by the heavy line.

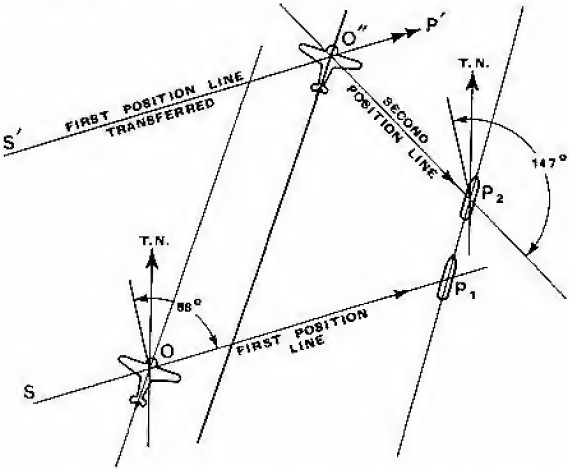

Fig. 462.—Running Fix of Aircraft by Two Bearings of Ship Transmitter.

Combination of Wireless Position Lines with Astronomical and Other Data. It is, of course, common practice for wireless position lines to be combined with other means of navigation, such as soundings or astronomical position lines in order to get a fix. A further instance of this is shown in Fig. 463, where the aircraft, on crossing a coast line, notes the true bearing of the station P to be 25°, which at once gives a fix provided that the line of the coast is such that an ambiguity cannot exist.

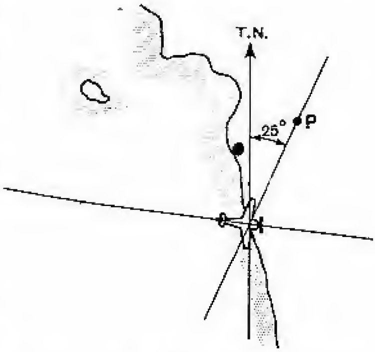

Fig. 463.—Aircraft Fix at Intersection of Wireless Position Line and Coast Line.

Wireless Fix by Bearing and Distance from a Fog Signal Transmitter. Certain W/T Fog Signal Transmitters, which may be installed either on shore or in light-vessels, operate a submarine or air sound signal synchronously with the wireless signal, thus enabling the distance between the sound transmitting station and the ship receiver to be found very simply by observation of the time taken for the submarine or air sound to reach the ship. This figure, in seconds, when multiplied by the factor 0·8 for submarine signals and 0·18 for air-borne signals, gives the approximate distance in nautical miles. In such a case, a true bearing of the wireless transmitter and a knowledge of the distance of the sound transmitter (usually near to one another) will give a fix.

The measurement of the time taken for the submarine sound to reach the vessel is simplified in some cases by the transmission of a series of wireless dots or dashes starting at the instant of synchronization. The time intervals of these signals, namely $1\frac{1}{4}$ seconds, are such that by counting the number of them between the instant of synchronization and the instant of arrival of the submarine signal, the distance in miles is given direct.

Obvious precautions are necessary as to the method of counting and the care with which the fraction of the final interval is observed. The counting, from the instant of synchronization should, of course, start "0, 1, 2, 3, etc." and not "1, 2, 3, etc."

As already mentioned, a list of W/T Fog Signals and Beacons is included in Vol. I of the Admiralty List of Wireless Signals, from the 1937 issue of which the following has been reproduced* as an example.

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* By kind permission of The Controller of H.M. Stationery Office. See important notice on page 546.

2014 **Bar Lt. V.** (Liverpool) **(GGM)** 53° 32′ 26″ N. 3° 19′ 19″ W.
WAVE: 306·5 kc/s (979 m.). TYPE: A2. POWER: 54 m.-a.
W/T FOG SIGNAL, every 6 min., commencing at the hour.
GGM (— — · — — · — —), etc. .. 50 sec.
Long dash (————) .... 7 ,, (1 min.)
GGM (— — · — — · — —) once. 3 ,,
Synchronous Signals:
Silent .... 10 sec.
GGM (— — · — — · — —) twice. 6½ ,, (18 sec.)
Dash (—) " Warning signal " .... 1½ ,,
Silent .... 20 ,,
GGM (— — · — — · — —) twice. 6½ ,, (28 sec.)
Dash (—) " Warning signal " .... 1½ ,,
Silent ....254 ,, (4 min. 14 sec.)

Total period .....360 sec. (6 min.)

SUBMARINE FOG SIGNAL:
GGM (— — · — — · — —) once.

SYNCHRONIZATION.—Submarine fog signal begins at the instant W/T " Warning Signal " ceases.

NOTE.—In addition to the synchronous signals, the submarine fog signal will be sounded for 10 seconds between the 3rd and 4th minutes and between the 5th and 6th minutes of the W/T fog signal period.

CLEAR WEATHER TRANSMISSIONS.
Times: At 12 and 42 minutes past each hour.
Signal: Two emissions of the W/T fog signal, *omitting* the signals for synchronization (i.e., silent interval is 5 minutes).

GOOD BEARINGS *to* (reported): 090°—160°, when clear of Isle of Man.

QTG Signals. Some Coast W/T Stations have special transmissions for D.F. purposes. Land's End (GLD) has been mentioned as having a service of this type and Niton (GNI) also transmits for one minute on request for a QTG. A charge is made.

Examples of two further stations are reproduced below* from Vol. I of The Admiralty List of Wireless Signals.

HONG KONG

488 **Cape d'Aguilar (VPS).** 22° 12′ 39″ N. 114° 15′ 11″ E.
WAVE: (A) 8,330 kc/s (36·01 m.). TYPE: A1. POWER: 0·25 kW.
(B) 500 kc/s (600 m.), 425 kc/s (705·9 m.), 375 kc/s (800 m.). TYPE: A2. POWER: 0·1—2·0 kW.
HOURS: (A) 0001—1600, 2220—2400. Keeps watch on 8,280 kc/s (36·23 m.). (B) Continuous.
Traffic lists: 0535—0545, 0635—0645, 1335—1345, 2235—2245 and 2335—2345. On completion of traffic list, station can receive calls on 143 kc/s and arrange for exchange of traffic on the alternative frequency of 103 kc/s, on which it transmits ship traffic. It receives on 125—150 kc/s (2,400—2,000 m.) by arrangement.

* By kind permission of The Controller of H.M. Stationery Office. See important notice on page 546.

Listens for calls on 8,280 kc/s (36·23 m.) : 2200—1600, 1730—1800.
QTG Signals : Wave : 300 kc/s (1,000 m.). Type : A2. Transmits free, on request, a series of the letters MO (— — — — —), followed at intervals by DE VPS. (Call Frequency : 500 kc/s). Continuous transmission during fog.
No responsibility is accepted for the bearings taken.
Good Bearings *to* (reported) : 015°—035° ; 250°—340°.

SIBERIA (Arctic Coast)

985 **Yugorski Shar.** 69° 49′ 12″ N. 60° 45′ 33″ E. (*P.A.*).
Wave : (**UCX**) 500 kc/s (600 m.), 439·9 kc/s (682 m.), 300 kc/s (1,000 m.), 142·9 kc/s (2,100 m.), 137·9 kc/s (2,175 m.). Type : A1, A2. Power : 2·0 kW.
(**UCX1**) 8,230 kc/s (36·45 m.), 6,210 kc/s (48·31 m.), 6,175 kc/s (48·58 m.), 5,540 kc/s (54·15 m.), 4,140 kc/s (72·46 m.) 4,060 kc/s (73·89 m.) 3,155 kc/s (95·09 m.). Type : A2. Power : 0·25 kW.
Hours : 0415—0600, 0800—1000, 1200—1400, 1600—1800.
QTG Signals : Wave : 300 kc/s (1,000 m.).
Time : First five minutes of each hour of shipping watch.
Signal : UCX UCX UCX Ü (· · — —), etc., for 5 minutes, UCX UCX UCX $\overline{\text{VA}}$.
Note.—This will be transmitted slowly, with intervals between signals of not more than 2 seconds.

PRECAUTIONS NECESSARY IN THE USE OF THE SHIP D.F.

Selection of Beacons or Shore Transmitters. For the ship fitted with D.F. apparatus and wishing to obtain bearings on fixed points ashore, very large numbers of Coast W/T Stations, Fog Signal Transmitters and special Wireless Beacon Transmitters are now available.

Whilst the procedure is simple, it is necessary to mention a number of precautions that must be observed, the one given immediately below being applicable to practically all cases of bearings taken of shore transmitting stations.

Arcs of "Good Bearings to" a Shore Transmitter. As soon as D.F. apparatus began to come into common use in ships, information was received from telegraphists regarding apparent arcs of good and bad bearings in relation to certain transmitting stations. In the 1927 edition of this book there was given one of a series of small maps issued by the Marconi International Marine Communication Company which indicated the arcs of good and bad bearings of transmitters on the N. Atlantic Ocean service.

The errors in the bad sectors are usually caused by coast refraction or by screening due to mountains in the path of the wave.

In the extracts from the Admiralty List of Wireless Signals given opposite, it will be noticed that bearings on Cape d'Aguilar are reported good only between 015°-035° and 250°-340°.

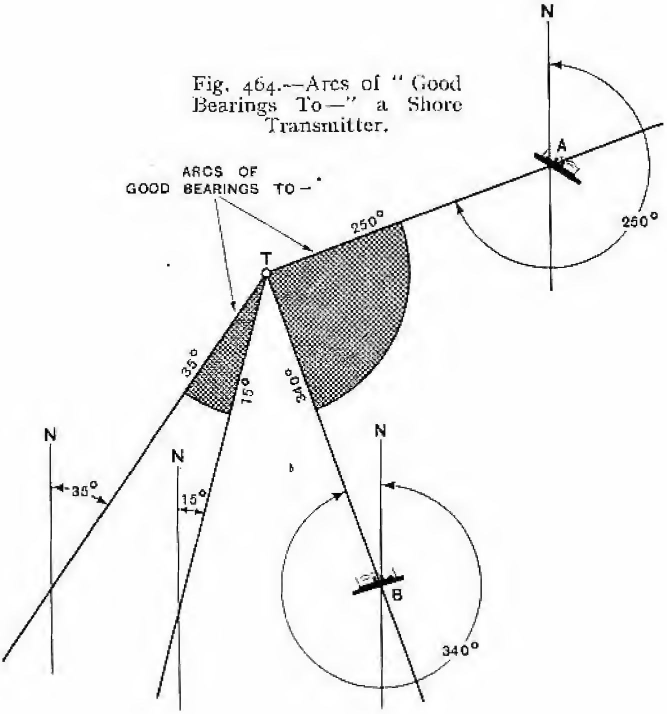

Fig. 464.—Arcs of "Good Bearings To—" a Shore Transmitter.

Note particularly that this is represented by the arcs shown shaded in Fig. 464 where the bearing from A *to* the transmitter is 250° and similarly the bearing from B *to* the transmitter is 340°.

Sometimes the information regarding the sector is modified by the distance of the ship from the W/T Station, owing to intervening land which causes screening. In other cases the good bearing sector is limited to a few degrees or it may be stated that bearings are unsatisfactory from all directions.

If no information is given on this point, it means that no bad bearing sectors have so far been reported.

Position of the W.T. Station. In certain instances, a bearing may be taken of a transmitter associated with a D.F. receiving station. In such a case it is possible that the transmitter and receiver may be widely separated, and whilst the position of the D.F. receiving station must be used when laying off a position line given as a bearing *from* the D.F. station, care must be taken to use the transmitter site position in the case of a bearing from a ship *to* the shore transmitter.

Emergency Transmitters. Some coastal stations have emergency transmitters at a distance from the regular one. (Vancouver VAB is such a case). When wishing to take a bearing on a station of this type, it is obviously necessary to send a QTG first to ensure getting proper information as to the transmitter in use, unless the transmitters can be identified, beyond any possible doubt, by means of their notes.

Polarization Errors. Apparatus for D.F. installed in ships and aircraft is usually of the kind susceptible to polarization errors, so that the distance of the transmitter, the wave length and the time of day must be taken into account in order to avoid errors due to " night effect." (See Chapter 6).

Precautions when Homing with the Ship D.F.

Allowance for Tide and Current. In Chapter 13, the effect of drift was described on the homing track of an aeroplane. This was introduced in connection with aircraft because homing is a recognized method of navigating in the air, and also because the drift in the air may assume velocities of 50 m.p.h. or more.

When a ship D.F. is being used for homing, however, it must be remembered that, apart from the danger of collision mentioned below, there is again the risk of being carried far off the straight course to the beacon by the effects of tide and current, although the ship's head be still pointing towards the transmitter. Fig. 388 illustrates the aircraft case and the danger of a corresponding divergence from the proper course in waters where the navigable channels are narrow need not be stressed.

The remedy is to maintain a constant magnetic compass course and to make allowance for the effect of the tide and current by swinging the loop away from the athwartship position, in the way described on page 498.

Collisions with Light Vessels. A number of serious accidents have occurred owing to ships using, as a " homing " signal, the W/T Fog Signal transmitted from a light vessel, shaping a course straight for the vessel and relying upon hearing the sound fog signal in time to change course and pass safely.

It seems almost incredible that such foolhardy methods should be adopted, but such has been found to be the case and a caution against the practice now appears in most publications relating to wireless navigation.

Avoidance of Collision Between Ships.

Whenever a ship (A) hears very strong wireless signals from another ship (B) during fog, and the bearing of B is found to be on the *bow*, a watch should be kept to ascertain whether the condition of *constant bearing and increasing signal strength* exists. If so, there is a grave chance of a collision, and the position becomes more serious for A if the bearing be on the starboard bow, as in this case it is the duty of A to keep clear. The condition is shown diagramatically in Fig. 465.

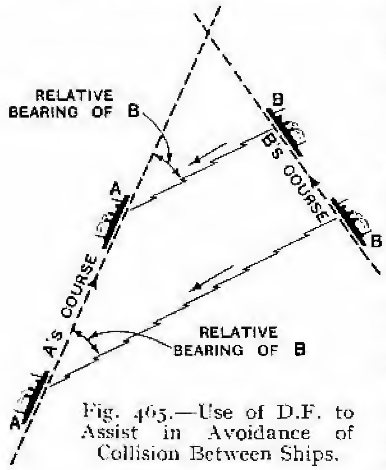

Fig. 465.—Use of D.F. to Assist in Avoidance of Collision Between Ships.

By keeping watch on the bearings, it is possible to detect whether the other ship is drawing ahead or astern, and in case of doubt a call can be given to find out her course.

It should be remembered that when a ship is at a considerable distance away, say 50 miles, the bearing may remain constant for a long period without danger, and the telegraphist should attempt to estimate the probable distance judging by the strength of signals—which should be quite a feasible thing to do after reasonable experience with the receiver in use.

USE OF D.F. BY SHIPS AND AIRCRAFT IN DISTRESS

Ships in Distress. A procedure rather similar to that which has been deprecated above as being a danger to Light Vessels may in certain cases be carried out with advantage. In the case of a distress call, when the vessel concerned sends her position, it is often preferable to attempt to find her by keeping her signals at 0° on the D.F. scale and ignoring the position given. Cases have occurred in which the estimated position was given 100 miles in error, and as long as the ship in distress is able to make signals with her wireless transmitting set, the above methods afford the most rapid way of finding her, though it remains a risky procedure in fog.

The value of a D.F. installed in a ship that is in distress is also demonstrated by her ability to give her bearings relative to other vessels answering her call, thereby enabling them to take the shortest route to her assistance.

Flying Boats in Distress. Aircraft making long oversea flights will, in the normal course of their navigation, keep in touch with shipping in the neighbourhood in order to plot their positions by D.F. relative to the ships, the positions of which may be fairly accurately known and can be supplied by W/T. If in danger of being forced down and a " MAYDAY " (the R/T aircraft distress call) or an " SOS " be sent out, followed by a distress message, the International Radiocommunication Regulations (1932) state that (Art. 22 E) the aircraft " endeavours to send its call sign for a period long enough to permit direction finding stations to determine its position." This is clearly the wisest procedure when in range of coastal D.F. stations or of ships fitted with D.F., particularly as all stations should be giving full attention to the distress call.

If, on the other hand, ships in range have no D.F. fitted or if any confusion should arise, it may be preferable to take the true bearings of ships that are transmitting and to advise them, repeating the bearings as long as main power holds out or until acknowledgements are received. The ships can now if they wish, steer on the reciprocals of the bearings given and this should bring them near to the spot, subject to convergency and other errors. The emergency transmitter can be used sparingly during later stages of the search if required in case of fog. In good visibility, day or night, it should scarcely be required if rockets, Very lights or smoke apparatus are available.

The ship working will not, of course, be heard by the terminal air port D.F. stations, which will be keeping watch on a scheduled short wave, but the ships will duly advise their coast terminal stations when time permits.

This is a method that has proved its worth in the past, but may require modification to fall in with the future organization of long distance flying services.

Aeroplanes in Distress. The aeroplane in danger of being forced down without power in inhospitable country is often in a worse predicament than is the flying boat as, even if a good landing be made, the position may not be accessible. In such a case the control station or stations would be advised and the urgency for bearings to be taken would depend entirely on whether the location of the landing place were known or not.

Again the advisability of conserving battery power is clear, for, if the aircraft be in an inconspicuous position or partly obscured by trees, the searching aircraft may fail to see anything and pass by unless attracted by W/T. The loop D.F. may also be used for obtaining bearings of searching machines, whose task will be simplified if these can be transmitted and their reciprocals used as courses.

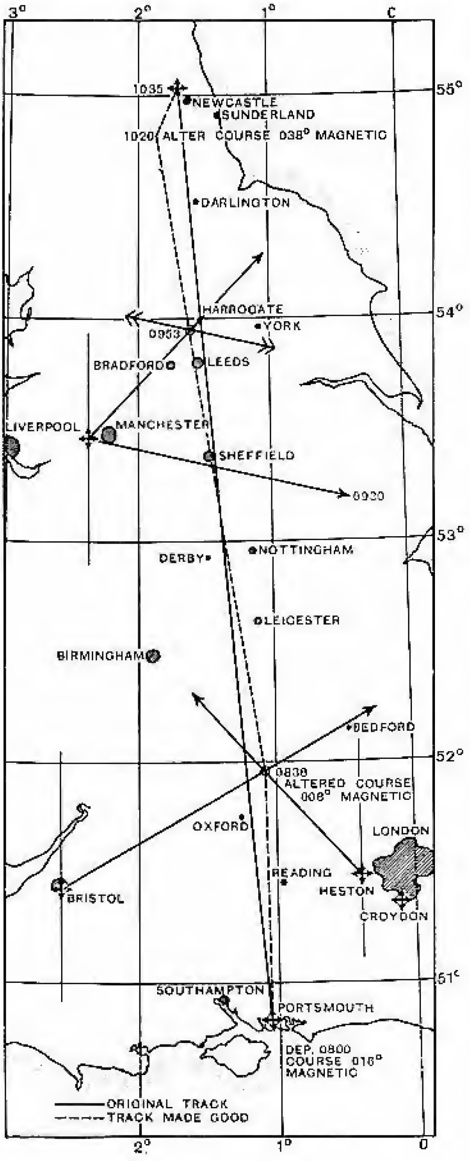

Fig. 466.—Example of Use of Ground Station D.F. Bearings by Aircraft (Imaginary Flight). (*Based on Ordnance Survey Map with the approval of the Director-General, Ordnance Survey, and of the Controller, H.M. Stationery Office.*)

An advantage of a shore landing is that there is a chance of a good aerial being rigged, giving better range on low power.

EXAMPLES OF WIRELESS POSITION FINDING

The instances of wireless position finding that conclude this chapter are not to be considered as instruction in navigation; for this purpose reference should be made to a text-book on air or marine navigation The four examples represent, however, fairly typical use of wireless bearings and show the application of some of the principles set out in this chapter and in Chapter 8, which dealt with maps.

Example of the Use of Ground Station D.F. Bearings by Aircraft. A flight is to be undertaken from Portsmouth to Newcastle, by an aircraft whose cruising air speed is 130 m.p.h. Departure is made at 0800 hours. The weather report gives a wind of 20 m.p.h. from east. This requires that the course shall be 016° Magnetic, the ground speed works out at 131 m.p.h. and E.T.A. (Estimated Time of Arrival) at Newcastle 1013.

It is now assumed that cloud is entered, and the ground not seen for the purposes of fixing the position until the aircraft comes below cloud again shortly before landing at Newcastle (Fig. 466). It should be noted that the flight is a purely fictitious one and no consideration has been given to any regulations that may govern the issue of bearings to aircraft in the different areas traversed.

At 0838 a request for D.F. bearings is made. Bristol gives QTE 059° and Heston QTE 318°. This fixes the position at a point some 6 miles to the east of the track, and by a quick computation with a "Course and Speed Calculator" it is found that the wind has changed and is now 11 m.p.h. from 040°. Using the same instrument the new course necessary to reach Newcastle is found to be 008° Magnetic and the revised E.T.A. 1022.

Fifty-two minutes later at 0930 a single bearing, QTE 102°, is given by Manchester. This bearing by itself will not, of course, fix the position, but since it crosses the track at a good angle it will give a useful check on the ground speed that the aircraft is making. Calculation shows this to be 109 m.p.h. This 0930 bearing, in conjunction with the ground speed that has been estimated will, however, be useful in working a running fix on to the second QTE—this time 043°—sent from Manchester after a further 23 minutes at 0953. The 0930 bearing is now transferred 42 miles up the track (i.e., 109 m.p.h. for 23 minutes), and where this transferred position line cuts the second QTE is the estimated position at 0953. This works out as 5 miles S.W. of Harrogate, which is about 5 miles west of the desired track. For the aircraft to have been in this position, the wind experienced will have been 23 m.p.h. from 025° True. Ground speed has been 112 m.p.h.

In view of the wind direction, it would not be unreasonable (in the present instance) for the aircraft to continue on her present course although this is taking her somewhat to the west of Newcastle aerodrome. By continuing until about 1026, the remaining track to be made good should be exactly upwind, that is to say the aircraft will have no drift as she approaches the aerodrome.

As soon as a QDM (Magnetic track to reach me) of 038° is given by Newcastle which, as has been shown, should be at 1026, this angle should be set on the compass after any necessary allowance for magnetic deviation has been made. As Newcastle is approached, further QDM's will be given which, because the aeroplane is coming in upwind, should not vary. Any slight alteration would be compensated by making the same alteration in the compass reading. The aeroplane must thus come directly over the aerodrome and the simplicity of this means of approach explains the great popularity of the QDM.

In the unlikely event of the aeroplane passing over the aerodrome without seeing it, this would be notified by a sudden 180° change in the bearing given by the ground D.F. station.

According to calculations the aircraft should now come into Newcastle at 1035.

Example of a Fix by Long-Range Cross Bearings. In selecting an example of a wireless fix over a distance of 500 to 1,000 miles or more, the use of bearings taken by a mobile D.F. cannot be taken as typical. Over such ranges, medium and long wave lengths would be useless at night owing to polarization errors, apart from the difficulty of finding suitable transmitters. Short waves cannot as yet be successfully used by D.F. apparatus in ships or aircraft except over limited ground ray range when using the pulse D.F. and the above ranges would also be too great for this system, when using medium waves, for the reason given on page 675.

An example of position finding by ground D.F. stations is, however, given by the projected trans-Atlantic air service for which the terminal stations as Foynes and Botwood are equipped with short-wave Adcock direction finders. On these flights, astronomical navigation is normally used, with confirmation by wireless cross bearings or running fixes on ships with which the aircraft is in communication. The long-distance bearings from the airports cannot be used to give a fix since, even with the aircraft badly off its course, the cut made by the position lines would still be at too acute an angle. The bearings nevertheless provide a continuous check on the track being followed and would be of value in an emergency.

For the sake of this example, a third short-wave D.F. station has been assumed to be available on the north coast of the island of Fayal in the Azores and, taking the position of the aircraft to be two thirds of the way across on the westward flight, the procedure in plotting a fix by bearings from these three D.F. stations is given below.

At intervals of an hour, or possibly more frequently, the aircraft reports its D.R. (dead reckoning) position to the terminal stations and concludes this transmission by sending a long dash for the purpose of taking bearings. Some five or more snap bearings may be taken by each station during the period of the dash, these bearings being rapidly averaged and the mean value, to within the nearest half degree, is sent to the control station and thence to the aircraft.*

The mean bearings for the transmission concerned in this example are found to be, say :—

Foynes	276°
Botwood	77°
Fayal	333°

and the D.R. position is given as 51° 15′ N., 38° 15′ W.

(NOTE.—The real position of the aircraft has been taken as being 50° 40′ N., 38° 10′ W. for the example and errors of +1, +1½ and −1 degrees have been introduced in the above true bearings).

To Plot the Fix on a Gnomonic Chart. The use of a gnomonic chart has the advantage that great circles are represented as straight lines and that no convergency correction is required but, on the other hand, there are three D.F. stations and bearings can only be laid off accurately when the D.F. is at or near to the point of contact of the chart. Special protractors must therefore be calculated and drawn for each station (page 261) and Fig. 467 shows a sketch of such a chart on which the three position lines have been plotted.

As mentioned previously, the centre of the triangle does not always give the most accurate fix and, in this instance, since the distances from Foynes, Botwood and Fayal are 1,150, 700 and 800 nautical miles respectively, the fix may reasonably be plotted nearer to the last two position lines than to the first, namely in Lat. 50° 33′ N., Long. 38° 50′ W.

To Plot the Fix on a Mercator's Chart. Gnomonic charts would undoubtedly be carried in the aircraft, but if it be wished to apply the wireless position lines to the nautical chart that is invariably used for astronomical navigation, corrections for convergency must be applied to the observed D.F. bearings.

The positions of the D.F. stations and the D.R. of the aircraft are as follows :—

---

* The procedure mentioned in this example is not necessarily that used in the actual flights ; the positions of the D.F. stations are approximate only, and the short-wave D.F. station on Fayal is purely imaginary.

Foynes ..	52° 47′ N., 08° 56′ W.
Botwood ..	49° 07′ N., 55° 22′ W.
Fayal ..	38° 40′ N., 28° 42′ W.
D.R. of Aircraft	51° 15′ N., 38° 15′ W.

The half convergency is now found for each bearing :—

Foynes
$$\begin{cases} \text{Diff. Long.} = 38^\circ\ 15' - 08^\circ\ 56' = 29^\circ\ 19' \\ \text{Mid. Lat.} \quad = \dfrac{52^\circ\ 47' + 51^\circ\ 15'}{2} = 52^\circ\ 01' \end{cases}$$

Half-convergency from diagram (Fig. 242) $= 11\tfrac{1}{2}^\circ$.

Remembering that great circles on the Mercator's chart are concave downwards in the northern hemisphere, (or by reference to Fig. 241 and associated table), it is seen that the correction for the Foynes bearing must be subtracted from the great circle figure to give the rhumb line bearing.

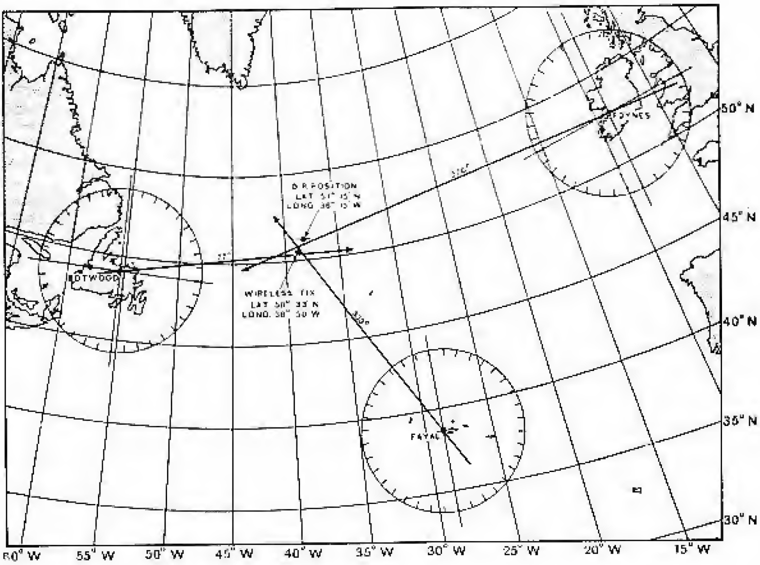

Fig. 467.—Long Range Wireless Fix by Ground Station D.F. Bearings Plotted on Special Gnomonic Chart. *(Based upon Admiralty Chart by permission of the Controller, H.M. Stationery Office, of the Hydrographer of the Navy and of the Secretary for the Air Ministry.)*

In a similar way, the other two corrections are obtained and applied, giving :—

	Observed True Bearing	Half Convergency Correction	Rhumb Line Bearing
Foynes ..	276°	$-11\frac{1}{2}$°	$264\frac{1}{2}$°
Botwood ..	77°	$+ 6\frac{1}{2}$°	$83\frac{1}{2}$°
Fayal ..	333°	$- 3\frac{1}{2}$°	$329\frac{1}{2}$°

These position lines are shown plotted in Fig. 468, where it will be noted that the Botwood and Foynes lines do not intersect. This is due to the respective mercatorial bearings being, in any case, within 3° of being reciprocal, and the errors in the bearings have resulted in their being almost parallel on the Mercator's chart although they were seen to intersect on the gnomonic chart.

This is a good example of the advisability of disregarding a fix given by two acute position lines since it is here found that the errors of 1° and $1\frac{1}{2}$° (See page 606) in the bearings have made the intersection occur somewhere off the chart. The fix may in such a case be taken on the Fayal position line and in, say 50° 30′ N., 38° 30′ W.

Example of Long-Range Fix by Cross Bearings Taken from the Aircraft. On the assumption that improvements in short-wave mobile D.F. apparatus will make it possible to take reasonably accurate bearings from a ship or aircraft over great distances, the above example has been modified below to

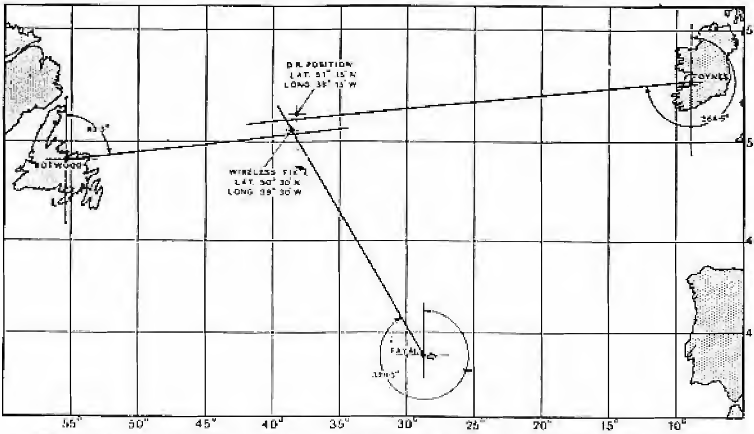

Fig. 468.—Long Range Wireless Fix by Ground Station D.F. Bearings Plotted on Mercator's Chart. (*Based upon Admiralty Chart by permission of the Controller of H.M. Stationery Office and the Hydrographer of the Navy.*)

represent the case of the mobile D.F. The positions of the transmitting stations are taken as being the same as the D.F.'s in the first case, the D.R. position of the aircraft is assumed to be the same as before and the observed true bearings from the aircraft are as given below. Again it is assumed that each of the bearings given is the mean of a series of readings taken in rapid succession during a period of a minnte or two.

Transmitter		Mean Observed True Bearing
Foynes	..	73°
Botwood	..	270°
Fayal ..	..	146°

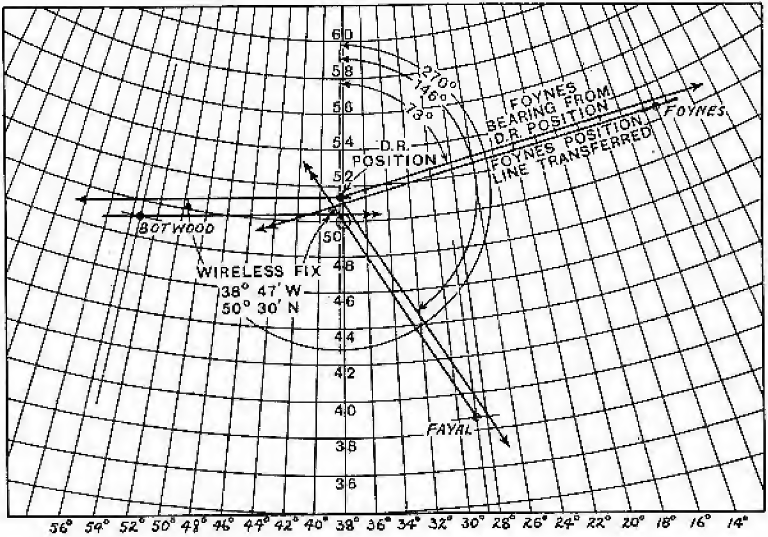

Fig. 469.—Long Range Wireless Fix by D.F. Bearings Plotted on Gnomonic Graticule. (*Based, by permission, on Graticule published by Marconi's Wireless Telegraph Co. Ltd.*)

To Plot the Fix on a Gnomonic Chart. Since all the bearings were taken from the aircraft and are to be plotted from the D.R. position the necessity for specially calculated protractors on the gnomonic chart does not now occur. Given that the D.R. position of the aircraft, when the bearings were taken, was 51° 15′ N., 38° 15′ W., a gnomonic chart or graticule must be selected, the point of contact of which is within a few degrees of this position. If a graticule be used, the method of locating the D.R. position and of numbering off the meridians, etc. has already been described on page 579.

Fig. 469 illustrates a graticule having its point of contact in

Lat. 50° N., the centre meridian having been called 38° W. to correspond approximately to the D.R. The three observed true bearings are now plotted from the D.R. position and are then transferred, using parallel rule or other similar means, to pass through their corresponding transmitting stations, giving a fix in Lat. 50° 30′ N., Long. 38° 47′ W.

To Plot the Fix on a Mercator's Chart. For this purpose the half convergency correction must be applied, with the appropriate sign. The D.R. position and other positions are all the same as in the example on page 606 where the method of obtaining the corrections was described. Note that since the bearings are in this case taken *from the aircraft* instead of from the shore stations, the signs of the corrections are all reversed. (See Fig. 241 and associated table for reason for this).

TRANSMITTER	MEAN OBSERVED TRUE BEARINGS	HALF CONVERGENCY CORRECTION	RHUMB LINE BEARING	RECIPROCAL
Foynes	73°	$+11\frac{1}{2}°$	$84\frac{1}{2}°$	$264\frac{1}{2}°$
Botwood ..	270°	$-6\frac{1}{2}°$	$263\frac{1}{2}°$	$83\frac{1}{2}°$
Fayal	146°	$+3\frac{1}{2}°$	$149\frac{1}{2}°$	$329\frac{1}{2}°$

There is now no need to lay off the rhumb line bearings from the D.R. position and to transfer them to intersect the transmitter positions. A rhumb line bearing intersects all meridians at the same angle on a Mercator's chart and so the reciprocals (*i.e.* bearing +180°) are laid off from the transmitter positions and the result is identical with that shown in Fig. 468.

Example of a Fix by Cross Bearings on Short-Range Stations :

(1) **Allowing for the movement of the ship during process.**

(2) **Using station pointer.**

(1) A ship in the English Channel is in estimated position 49° 29′ N., 4° 48′ W. at 1710 on a course N. 58° E. Fog exists and previous wireless fixes having been obtained from neighbouring beacons, another fix is now required. It is noted that the ship's D.R. position is still within one of the arcs of "good bearings to" Round Island, which are given as 030°-225°, 280°-310° ; Ushant has a "good bearing to" sector of 036°-220°.

Ushant beacon transmits on 294·5 kc. (1,019 m.) every 6 minutes during fog, starting at 2 minutes past the hour, each transmission lasting 1 minute 50 seconds. Round Island is in the same group (see Fig. 368) transmitting on 294·5 kc. every 6 minutes during fog, but starting at zero of each hour, each transmission lasting 1 minute 45 seconds.

At 1715 a bearing of 191° True is obtained on Ushant and at 1719 a bearing of 293° True on Round Island.

It is now decided to get a third check bearing and as Lizard, in the same group, is not operating, whilst Rame Head beacon only transmits on request of certain liner companies, Start Point is selected, the estimated position of the ship being in the 255°-072° "good bearings to" sector of this beacon.

Start Point is in another group and works on 312·5 kc. (960 m.), again transmitting every 6 minutes during fog and starting at 2 minutes past the hour, namely, at the same times as Ushant. The 1720 and 1726 transmissions are missed due to other W/T work, but a bearing of 41° True is obtained at 1733.*

Since none of the beacons is far enough from the estimated position of the ship to introduce convergency errors, the reciprocal true bearings may be laid off from the beacon positions, namely, $191^\circ - 180^\circ = 11^\circ$ from Ushant; $293^\circ - 180^\circ = 113^\circ$ from Round Island and $41^\circ + 180^\circ = 221^\circ$ from Start Point, as shown by the position lines with single arrows in Fig. 470, in which the ship's track and previous fixes are also marked.

The triangle produced by the three lines does not give the position of the ship owing to the 18 minutes that elapsed between the taking of the first and last bearings. To find the position when the Start Point bearing was taken, it is therefore necessary to transfer the Round Island position line along the ship's track a distance equal to that travelled by the ship in 14 minutes, which, at 15 knots, is 3½ nautical miles. The transferred position line is shown with double arrow heads. Similarly the Ushant line, taken 18 minutes before the Start Point bearing, must be transferred 4½ miles along the track as shown.

It is now seen that the Start Point position line and the two transferred ones produce a triangle of about 8 square miles area, the centre of which is at 49° 33′ N., 4° 41′ W., and this may be taken as the ship's position at 1733.

Whilst this example illustrates the principle of the allowance for the movement of the ship, this would rarely be necessary in the English Channel as a delay of 18 minutes between beacon bearings would be exceptional. Such delays, however, might well occur in other parts of the world where suitable transmitters are not available when required or alternatively a discrepancy in time may arise when a wireless position line is being used in combination with astronomical data to give a fix.

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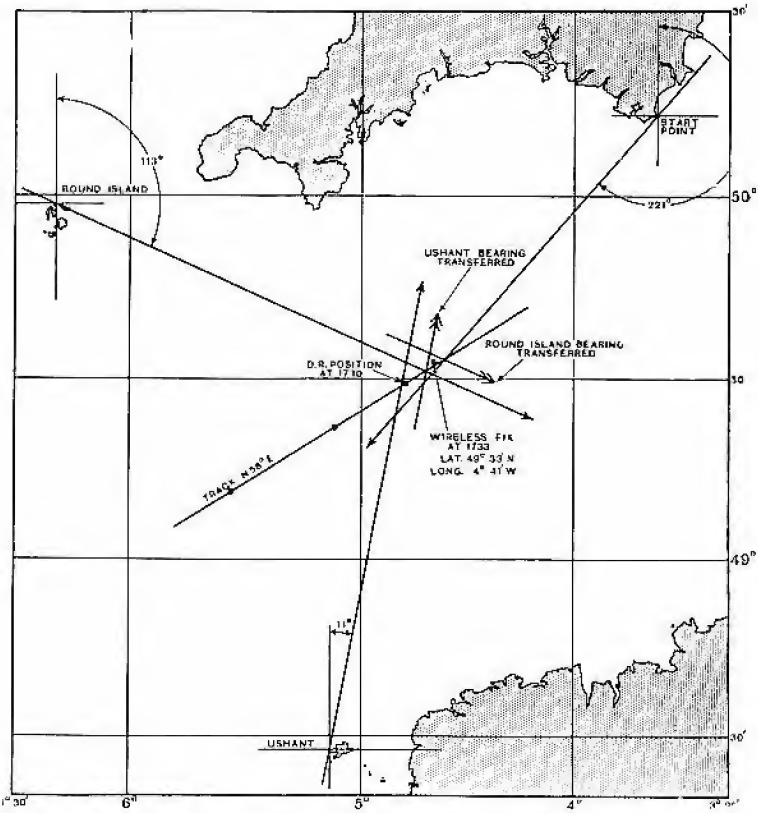
* Information regarding these beacons is taken from the 1937 issue of "The Admiralty List of Wireless Signals," Vol. I. See important notice on page 546.

(2) **The Station Pointer.** Had the above three bearings been taken within a space of a few minutes, the station pointer could have been used. There are two ways in which the instrument can be applied, the first being to make use of the true bearings of any two of the three transmitters, and the second is to use the subtended angles, at the ship, of all three stations in the way mentioned in connection with Fig. 459.



30'
ROUND ISLAND
113°
START POINT
221°
50°
USHANT BEARING TRANSFERRED
ROUND ISLAND BEARING TRANSFERRED
D.R. POSITION AT 1710
30
WIRELESS FIX AT 1733 LAT. 49° 33' N LONG. 4° 41' W
TRACK N58°E
49°
11°
USHANT
30'
6°
5°
4°

Fig. 470.—Short-Range Wireless Fix by Ship D.F. Bearings Plotted on Mercator's Chart. (*Based upon Admiralty Chart by permission of the Controller of H.M. Stationery Office and of the Hydrographer of the Navy.*)

In the first case, the centre leg of the station pointer will represent North, the right leg will be set to 191° to represent the Ushant position line and the left leg to 293° for Round Island. The instrument is then laid on the chart, with the centre leg parallel to a meridian, and the adjustable legs are arranged to pass through the respective transmitters, giving a fix. The same process can then be carried out for another pair of stations and the results compared.

In the second method, the direction of the meridian is ignored, and the three legs are set so as to include angles equal to those subtended at the ship by the three stations. Thus, suppose the centre leg to represent the Round Island position line, then the right leg will be set at $360° - 293° + 41° = 108°$ for Start Point, and the left leg at $360° - 293° + 191° = 258°$ for Ushant. The station pointer is then applied to the chart so that the three legs pass through the transmitting stations and a fix is obtained that will coincide with the centre of the first triangle of Fig. 470, that was produced by the three position lines before allowance was made for the discrepancies in the times of taking the bearings.

CHAPTER 15

AIRCRAFT APPROACH AND LANDING SYSTEMS

Introduction. In the previous three chapters, there have been described both directive beacon methods and radio compass methods by which a pilot or navigator might employ wireless aid in point-to-point navigation, or in homing approach to an airport. Alternatively, the position of the aircraft may be supplied, or the reciprocal magnetic bearing of the airport, or similar information obtained from a ground D.F. station. This data will be a valuable check on the dead reckoning position, will provide almost infallible assistance in the approach and will, in general, bring the aircraft to a position directly above the airport, regardless of the visibility conditions.

It is now that there arises the most pressing and most difficult problem in wireless navigation, namely, that of guiding the aircraft down to the runway. Once having arrived in the vicinity of the airport in weather that does not allow of landing by visual means, the heavier than air type of craft cannot remain in the air indefinitely, or be brought slowly into port at a mile or two an hour, or "heave to" to await better flying conditions. The pilot may, on the other hand, have to leave a region of clear sky and sunshine at several thousand feet and descend through cloud, rain, fog or snow blizzard to make a landing at 80 miles an hour on ground that remains invisible until a few moments before it is reached.

It is with this high-speed three-dimensional navigation that we are concerned in the latter part of this chapter, for, apart from the desirability of making safe the landing of passenger aircraft in poor visibility, increasing reliance is being placed upon the scheduled day and night departure and arrival of air mail, newspapers, and freight. More urgent than the civil requirements, however, is the necessity for a method of landing service aircraft during QBI* conditions and for all the above reasons, methods of blind landing must be perfected.

As mentioned already in the introduction to Chapter 12, it is not proposed to deal with the details of transmitter technique and design, but mainly with the general problem and with the principles of some approach and landing systems.

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* QBI=Bad visibility. See Q code extracts, page 560.

AIRPORT ORGANIZATION DURING QBI CONDITIONS

The systems of approach and landing can probably best be introduced by a brief mention of the organization of an airport when the visibility is bad. An undue amount of space would be occupied by a detailed account of the full procedure, but a very good idea of its scope, in so far as it affects D.F. approach and landing activities, can be had by reading through the Q Code extracts on page 560, sub-sections (*d*), (*e*) and (*f*).

In the following paragraphs definitions are given of some of the terms used in connection with approach and landing operations, together with an outline of the main precautions taken for the safety of aircraft desiring to land.

The Zone of Approach or **Controlled Zone** is a region surrounding an aerodrome, extending usually to 12 or 25 miles radius horizontally and to the vertical limits of flight and in which, during QBI conditions, the control station of the aerodrome has complete authority over all air traffic.

The Approach Sector is a corridor of approach to the aerodrome, which, by virtue of lack of obstructions or for other reasons, is recommended for use during QBI. Approach sectors are also selected with regard to the direction of prevailing wind during bad visibility.

The Axis of Descent is related to the Approach Sector and is an axis or glide path which it is desirable should be followed down to the runway. The tolerances to be allowed around this axis are usually specified.

Particulars of the limits of Zones of Approach, Approach Sectors and Axes of Descent are given in " Regulations for the International Radio-electric Service of Aircraft."

QBI Warning. When QBI conditions exist at an aerodrome, a warning is sent to neighbouring aerodromes and to aircraft in flight in the district. This may be cancelled by a QBI FIN signal or becomes automatically terminated at midnight.

Control of Aircraft Movements Outside Zone of Approach. An aircraft fitted with W/T or R/T and flying in limited visibility outside the zone of approach, is obliged to warn the aeronautical station with which it is in communication.

There remain other matters with which the aeronautical station deals during QBI conditions and it may, if necessary, request the delay of the departure of an aeroplane from a distant airport if there is congestion of traffic at the home aerodrome due to fog.

Control of Aircraft Movements within the Controlled Zone. The code groups relative to the " Controlled Zones " are given on page 560 and no aircraft may enter a controlled zone until permission has been given by the proper control station. Having entered the zone, permission must be obtained before landing, and this may be temporarily withheld and the aircraft despatched on a given bearing or to a stated height to await instructions.

After admission to the controlled zone, the groups of section (*d*) " Meteorological Advice During Flight " are used to allow of the checking of the aircraft's altimeter, for change in barometric pressure and for the height of the aerodrome above sea-level.

Special Radio Communication Service for Landing Operations. During the time that QBI regulations are in force at large airports, a special 932 m. (322 kc.) wave may be used for landing operations and, on entering the zone of approach, the following code groups are available for arranging this :

QSW 932 m. QSY 932 m.	I am going to transmit on 322 kc. (932 m.). Change over to transmission on 322 kc. (932 m.).

METHODS OF LANDING BY CO-OPERATION WITH THE AIRPORT D.F. CONTROL

At the time of writing (1938) none of the instrument methods of landing mentioned later can be considered completely satisfactory, and none has yet received the necessary approval of the British Air Ministry that would allow of its adoption in this country for all classes of flying services. In other countries, particularly in Germany and America, the methods are claimed to be somewhat more advanced, but there remains much to be done before their reliability reaches the degree necessary for their general use.

There are, however, certain systems of landing by co-operation between pilot and ground W/T staff which, though demanding a very high standard of flying skill combined with a knowledge of the aerodrome and faultless team work, have proved sufficiently workable in practice to meet with approval for both freight and passenger landing. The appropriate code groups are given on page 561 under " (*f*) Landing Procedures."

Penetration Method of Landing. If the height of the lower level of a bank of cloud or fog is sufficient to allow of an aircraft penetrating it with safety, the machine may be guided by D.F. to a position over or near the aerodrome and then advised QFH. The pilot then descends into the clear region, advises QBH and lands in the usual way.

"ZZ" Method of Landing. When the clouds or fog bank are low enough for obstacles surrounding the aerodrome to protrude, the penetration method cannot be used and the "ZZ" method is extensively employed in Germany. The contraction ZZ refers to zero horizontal and zero vertical visibility, but the system is not intended for use under these conditions and is still considered undesirable if the clouds are lower than about 130 feet and if the surface visibility is less than 300 yards.

Having entered the zone of approach, the aeroplane is guided to the aerodrome by D.F., using QDM bearings and is duly advised QGX. At the same time, the approach sector to be used is given, together with the barometric check QFE. This is illustrated in Fig. 471, where the approach sector is taken as 300° and the QFE 960 m.b.

As soon as the motor is audible above the aerodrome, the aircraft is given QFG, and it moves off on a course such that after turning it will be on the centre of the sector of approach and will require 7 or 8 minutes to fly back to the aerodrome. During this flight QDR bearings are the more convenient and are supplied as requested, and are repeated back.

The pilot estimates the duration of the outward flight required, and on turning he transmits the word "TURN" or its foreign equivalent and then flies back, using the QDM bearing and adjusting his course on receipt of each, and at the same time losing height so that a landing may be started when the aerodrome boundary is reached. When the noise of the motors is again heard, one of the following signals is made:

MN	Noise of motor North.	MS	Noise of motor South.
ME	Noise of motor East.	MW	Noise of motor West.

Landing Signal. On receipt of this advice, the pilot ceases transmission and, provided that all appears to the ground control to be normal and the aircraft is on its correct bearing, the landing signal is sent, consisting of the letters ZZ, with the last letter of the ground station call sign interposed. Thus Munich airport is DDP and the landing signal is ZPZ.

The aircraft now descends until the ground or flares are visible, and lands.

If, during the latter part of the approach, the ground control suspect that there will be difficulty in landing due to the aircraft having drifted off its course, the landing signal is not sent but there is transmitted in its place the letters JJ with the last letter of the ground station call sign interposed, in the above case, for example, JPJ. On receipt of this signal the pilot opens up and flies on until he receives further instructions.

Other D.F. Landing Methods. Whilst the ZZ method is one of the most systematic ways of landing with ground co-operation, there are modifications of it, peculiar to certain airports, that are equally effective when used by experienced pilots, and landings are carried out by mail and cargo aircraft under conditions of dense fog in emergencies.

Beacon Method of Landing. Beacon methods of landing also involve co-operation with the Airport Control Station, and after the preliminaries of entering the zone of approach

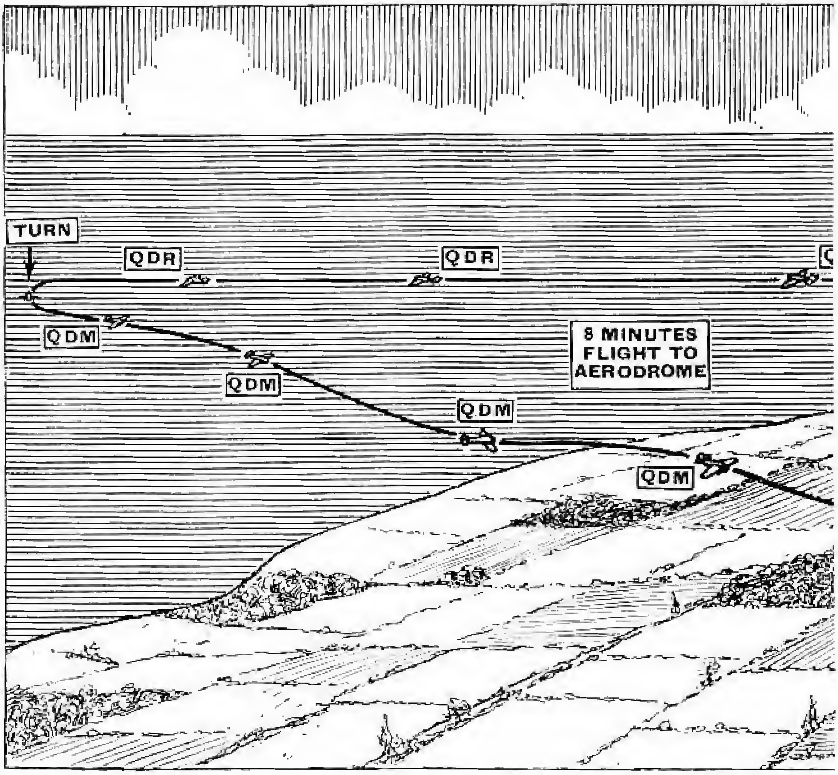
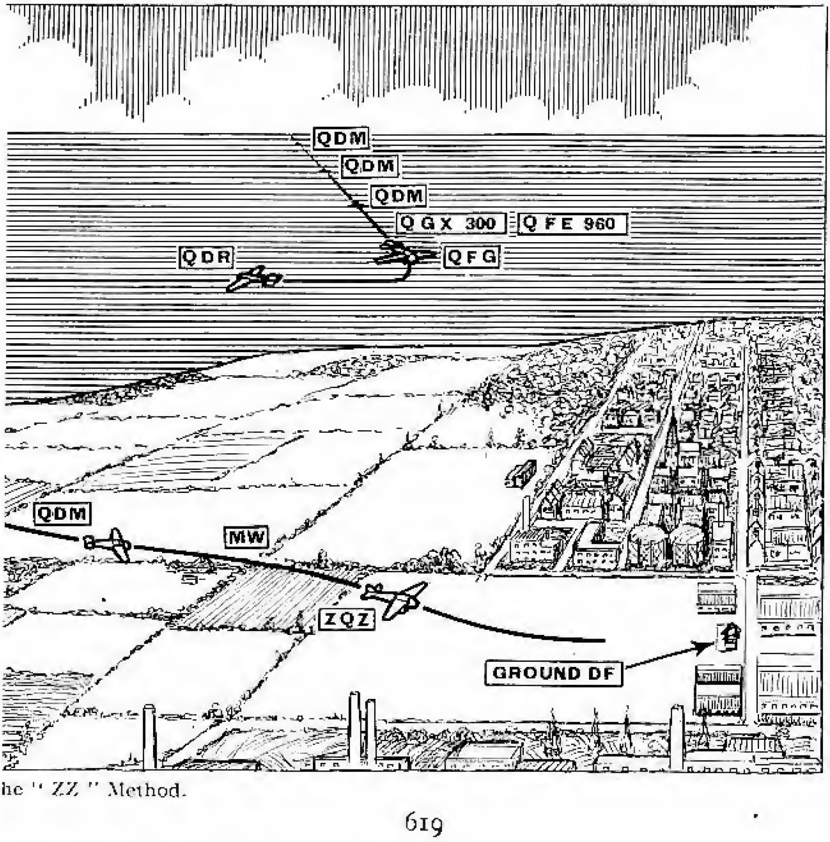


Fig. 471.—Landing

and obtaining permission or being instructed to land by the beacon method, the pilot is advised on which course he is to land—assuming the beacon to be a bi-lateral one. The pilot then flies to the equi-signal course, in which he may be assisted by D.F. bearings or in certain cases he may fly over the aerodrome as in the ZZ method, setting his course from there.

INSTRUMENT FLYING

Underlying all systems of approach and landing during QBI conditions is the general problem of instrument flying and the question of the stability of the aircraft during blind flight. Whilst all the systems described in the latter part of this chapter provide wireless guidance in one form or another, the process of maintaining the desired path is found to be greatly facilitated by reference to the instrument equipment



he " ZZ " Method.

used for aiding stability and straight flight. The following brief descriptions of this apparatus may therefore be of use to the reader who is completely unfamiliar with the subject.

The Directional Gyroscope. This instrument consists of a gyroscope mounted so as to be free about the three directional axes. The axle of the gyroscope is horizontal, in the true line of flight of the aircraft. A circular card, graduated in degrees, surrounds the vertical ring of the gimbal. The face of the instrument is screened, excepting for a small clear panel through which a section of the card appears.

Owing to the fundamental property of gyroscopic inertia, the rotor, when spinning, together with supporting ring and card, remains fixed in azimuth regardless of any yaw or turn during flight.

The instrument may be set to any desired course, but the gyro has no directive force to return it to a set heading, and it is therefore necessary to check and if necessary to reset the directional gyro about every 15 or 20 minutes.

The Artificial Horizon. In the artificial horizon, the axle of the gyroscope is vertical, and so mounted as to be free about the fore and aft and lateral axes. When spinning, the gyroscope tends to remain with its axle vertical, owing to gyroscopic inertia. Any tendency to depart from this attitude is counteracted by an ingenious arrangement of pendulous vanes on the gyro casing. These deflect the flow of air in such a manner as to keep the axle within two degrees of vertical under all conditions of flight. The face of the instrument is circular, and divided into two sections, the horizontal diameter representing the horizon as normally visible on level flight. An index bar, linked to the gyroscope, rests at the horizontal diameter in level flight.

The gyroscope, and therefore the index bar, retain position under all normal flight conditions and hence any manœuvre of the aircraft, e.g., climb, dive, bank, etc., will alter the position of the case of the instrument in relation to that of the index bar. Suitable markings on the glass of the case interpret these movements, giving a direct indication.

The Automatic Pilot. In principle, the control unit of the automatic pilot consists of two gyroscopes, mounted respectively in the same manner as the directional gyro, and the horizon gyro. These in their turn control, by means of servo motors, a battery of control rods, which operate directly on the normal flying controls. The directional gyro controls the rudder, while the other controls the movements of ailerons and elevators. The aircraft is held in true flight on its course, and any tendency to variation is immediately counteracted by action of the appropriate gyroscope operating the servo motor.

As in the case of the Directional Gyro, the directional unit of the automatic pilot must be checked and reset periodically.

Damper action is provided, in order to obtain the necessary degree of control according to weather conditions.

The Turn and Bank Indicator. Although there are several types of this instrument, the basic principles of operation are similar.

For turn indication, the properties of the gyroscope are used. The gyroscope is mounted with its axle parallel to the cross-axis of the aircraft, and carried in a frame which is pivoted about the fore and aft axis. This frame is usually restrained by springs or a gravity element, and normally rests horizontally when the gyro is not spinning.

When the gyro is spinning, a turn of the aircraft sets up precession, the degree of which is transferred to the dial as indication of turn.

Bank indication is usually by a gravitational device, either a steel ball in a crescent tube, or a pendulum.

A central reading is obtained when flying level, but tilt to either side will be immediately indicated unless associated with a turn such that the centrifugal force and gravity together maintain the ball central. Side-slip in the event of too flat or too steep turning is also thus shown.

The Air Speed Indicator measures the speed which an aircraft would be making through still air. An open-ended tube, called the pitot tube, facing directly forward in a position clear of the slipstream is attached to a wing strut. The flow of air causes an excess of pressure in the tube which is connected to the inside of a highly sensitive expansion chamber. When air pressure causes distension of this box, the movement is transmitted to operate a pointer moving over a dial calibrated in m.p.h. or in knots.

The Magnetic Compass is, of course, of primary importance and is widely used in conjunction with any form of wireless navigation. Whilst aircraft magnetic compasses are of special design, the principle is well known and further details are not necessary.

Rate of Climb Indicators or Meters. The commonest type of rate of climb meter is based on the capillary leak principle. The air chamber (the case of the instrument) contains a sensitive capsule. The inside of the capsule is connected to the outer air by a tube which leads to the static side of the pitot head. A tapping from this tube connects to a capillary tube inside the instrument case. Thus any change of pressure at the static head is immediately felt inside the capsule, but the effect in the instrument case is delayed by the small capillary leak.

On climbing, pressure in the case is in excess of that inside the capsule. The higher the rate of climb the greater the difference between these pressures. The consequent collapsing or dilating of the capsule is used to operate the pointer of the instrument.

The Altimeter is an instrument for registering the height of the aircraft. The principle on which it works is the same as the simple aneroid barometer, but the dial is calibrated in feet. The dial on modern types of altimeter can be rotated, so that an arrow is made to point to the exact barometric pressure existing on the surface of the airport of destination. This is of great value when landing in conditions of bad visibility as the pilot knows that his instrument will read zero, with a fair degree of accuracy, when the machine touches the ground.

Great care is necessary in the design of the aircraft barometric altimeter to ensure accurate reading under all conditions at low altitudes. Some uncertainty may exist due to a variety of causes but mainly to the possibility of fatigue of the spring that sustains the pressure on the capsule of the instrument, and fatigue of the capsule itself. This pressure is appreciably reduced at altitudes of several thousands of feet, and after some hours flying at these heights and a return to lower levels and higher pressures again, the spring may not return exactly to its original position, with a consequent altitude indication in excess of the true figure.

INSTRUMENT METHODS OF APPROACH AND LANDING

In 1930 a Research Paper by H. Diamond and F. W. Dunmore was published by the Bureau of Standards (3020) describing the application of the equi-signal beacon, during the years 1928 to 1930, to a system of blind landing for aeroplanes. About the same time, the Germans again took up the equi-signal beacon, which had originated with Scheller and the Lorenz Company some 23 years before. The Lorenz Company, of Berlin, have since produced a "thick weather" landing system that is installed at Berlin and other German and European airports and also at Heston, Gatwick and Croydon in this country. The Telefunken Company, of Berlin, have also developed a system similar to that of the Lorenz in many respects but differing in detail.

The principle of the European landing systems will be found to have much in common with the original Bureau of Standards system, although, in the U.S.A., the latter has recently been challenged by a modified form, developed by the U.S. Army Air Corps, in which the approach to the airport is by wireless guidance and the landing by altimeter, a combination that has much in its favour.

Whilst the technique of the modern methods is the more important it will be of some value, in gaining a correct perspective of the progress in approach and landing systems, to go back to 1929 and to note the pioneer American work on the subject.

THE U.S. BUREAU OF STANDARDS BLIND LANDING SYSTEM

The early history of the subject emerges out of the research on the equi-signal beacons already dealt with on page 474, and in 1929 tests were made with a runway localizing double modulation equi-signal beacon working on 330 kc. and with a range of about 15 miles. The procedure was to approach the airport using the radio range equi-signal beacon, which was located some distance from the aerodrome so as to avoid obstruction, the arrival over this beacon being indicated by the usual weakening of signals. At high altitudes the position could not be ascertained within about 1,000 feet, but by flying at about 1,000 ft. altitude the position could be fixed more accurately and the aeroplane then flew off on a magnetic compass course a distance of 5 to 10 miles to pick up the runway localizing beacon. This is illustrated in Fig. 472. The boundary marking beacon gave advice when entering the landing field and at this point reliance had to be placed on an altimeter to assist the pilot in his glide.

Hooded landings were made using a directional gyro to maintain a steady course and to avoid zig-zagging, but after all precautions had been taken it was difficult to ascertain the altitude accurately when near the ground and the landings, though achieved, depended to a large extent on the special oleo landing gear to avoid dangerous shocks.

The Dunmore Landing Beam. These landing tests led to the system shown in Fig. 473 which included, for the first time, the idea of the ultra-short wave glide or landing beam in the vertical plane, which was suggested by F. W. Dunmore (3020). The diagram, taken from the above reference, shows the relative positions of the beacons and their radiated polar diagrams.

As with the earlier system the pilot first picks up the medium wave length equi-signal runway localizing beacon at a distance of 5 to 10 miles from the aerodrome, and then, at a height of anything from 500 to 5,000 feet, endeavours to keep a steady course, using the visual indication given by the vertical pointer of the combined instrument shown in Fig. 474, the principle of which may be seen from the experimental model shown in Fig. 475. The common radio frequency receiver for the runway localizing and marker beacons was fitted with a filter device, whereby frequencies below 200 cycles—which included the modulation frequencies of the equi-signal runway beacon—were diverted to the operation of the vertical pointer, and the higher 1,000 cycle note of the marker beacon to telephones.

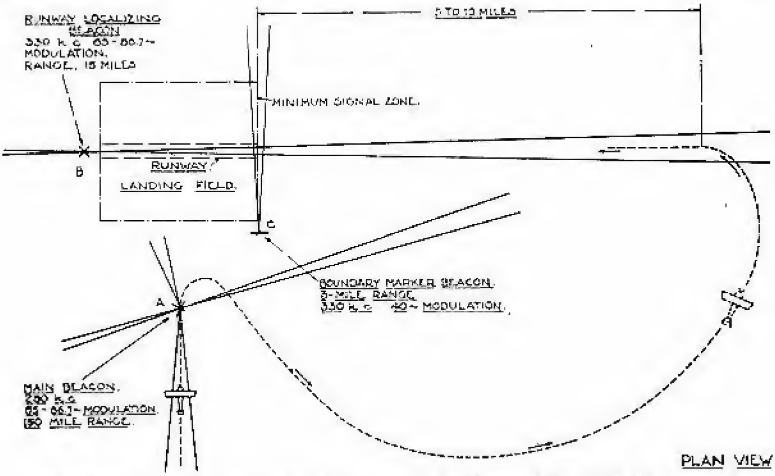


Fig. 472.—Early Equi-Signal Approach System of the U.S. Bureau of Standards (*Bur. Stand. Jour. of Research*).

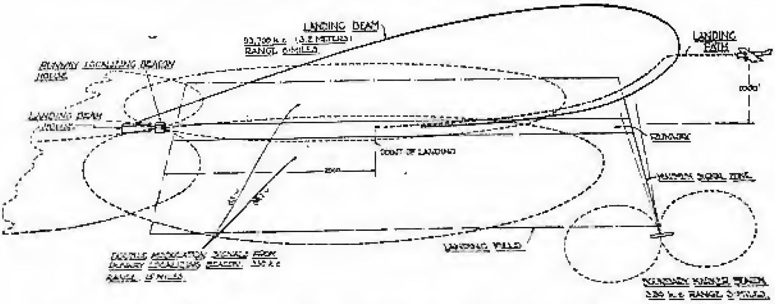


Fig. 473.—Application of the Dunmore Ultra-Short-Wave Landing Beam (*Bur. Stand. Jour. of Research*).

The low frequency modulation also operated auto-gain on the radio frequency amplifier so that saturation of the receiver should not occur as the runway localizer signal voltage increased in a ratio of about 1 : 50. The marker beacon audio frequency, having no effect upon the auto-gain, allowed the variation in the intensity of the signal to be observed as the aircraft passed through the vertical beam.

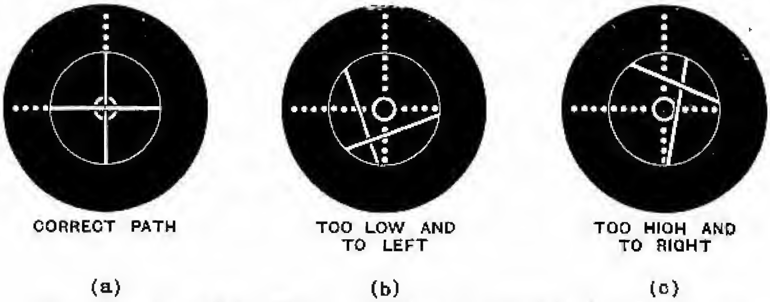


Fig. 474.—An Early Visual Indicator for Combined Lateral and Vertical Guidance (*Bur. Stand. Jour. of Research*).

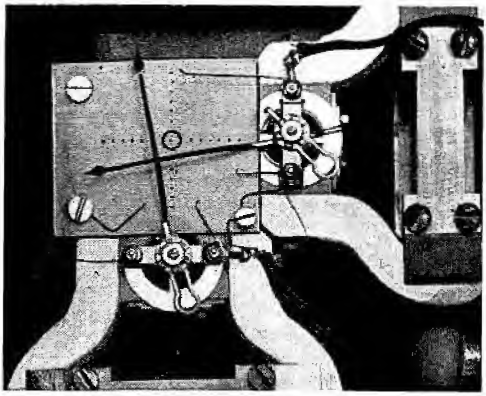


Fig. 475.—Experimental Model Indicator as in Fig. 474 (*Bur. Stand. Jour. of Research*).

The control voltage of the auto-gain was also used to indicate, by means of a milliammeter calibrated roughly in miles, the distance from the aerodrome.

Approaching the airport on the runway localizing visual indicator and when still some 4 or 5 miles distant, the horizontal pointer of the instrument of Fig. 474 begins to rise, this pointer being operated by the field of the landing beam beacon. It was arranged to have about half-scale deflection when the aeroplane, having entered the beam along the path A, for instance, in Fig. 476, had penetrated to a point P.

The pilot now starts a glide, keeping the pointer horizontal, showing that the path followed is along a line of equal field strength. It will be seen that the lower paths B and C will lead to the same glide path whilst, if the glide be started rather earlier, at Q, as shown by the lower curved line, the landing point will be almost the same.

Endeavouring, then, to maintain glide path and equi-signal course, the warning is received within a few minutes that the boundary beacon has been passed, and the speed must now be reduced to a few miles per hour above landing speed and the glide path held until the ground is reached.

Later Developments. In October 1933, a Research Paper (3320) was published giving particulars of later stages of the development of the system, the chief point being the addition of a second and more distant marker beacon. Two marker beacons are now commonly used in modern landing systems, and are approved by international regulations on the subject. There were also changes in receiving apparatus, improved types of indicators, and attempts to arrange for the mobility of the beacons to provide for different landing directions, in case of bad visibility combined with wind.

Throughout the Bureau of Standards Tests, the polarization of the landing beam radiation was horizontal, and reception was carried out on a copper tube dipole with a reflector of similar form, both attached to the top wing of the biplane used in the tests. The wave length was 3·3 m. (90·8 M.c.). The work of the Deutsche Versuchsanstalt für Luftfahrt (German Research Institute for Aviation) on vertical dipoles for the same purpose was progressing at the same time and is mentioned in (3320).

The above reference also contains particulars of very interesting early landing tests with the Dunmore beam, the first completed blind landing having been made on Sept. 5th 1931, by Pilot M. S. Boggs, using a hooded aeroplane. The same pilot subsequently made more than a hundred such landings on a runway only 2,000 feet by 100 feet, with a check pilot in the front cockpit in case of emergencies.

Landing by the Bureau of Standards System. An imaginary U.S. airport is shown in Fig. 477, with the track of an aeroplane making an approach and landing by the above system in its final stage of development. The diagram and account of the landings are based on a description of hooded landings made by E. A. Cutrell (3517).

At (1) and (2) the aircraft is approaching on a radio range beacon leg at a height of, say, 2,000 feet. At (3) when loss of the radio range signals indicates that the aircraft is over the beacon, a right hand turn is made through the appropriate angle that will bring it on to the marker beacon approach line. During the turn, height is lost at (4) and (5) by an amount that depends on meteorological conditions and on the type of aeroplane, and in this case is taken to be reduced to 800 feet.

It is now necessary to manœuvre the aeroplane on to the equi-signal line of the runway localizing beacon and at (7) the boundary beacon signal is obtained. The equi-signal path is now flown away from the airport for two minutes and, although visual indication of the adherence to the path is given by the meter, the intelligent use of flying instruments is as essential in this system as it is in the "Hegenberger" method described on page 644.

During the outward flight, if a steady equi-signal course is kept, the directional gyro will indicate the drift compensation that is being allowed and this figure can be used on the return flight with a correspondingly less chance of losing the course and pursuing a weaving flight in an attempt to regain it. If the first outward flight gives unsatisfactory results, the drift compensation observed may be used in a second attempt.

Assuming the outward flight to have been successfully carried out, position (8) is reached and here a 30° change in course is made to the right. After 45 seconds flight a 210° left turn is made (*i.e.* 30° + 180°), which will bring the aeroplane through (9) to (10) and thus back on the approach course. The height throughout is maintained by altimeter at 800 feet.

Keeping the vertical needle central, the approach is continued until the horizontal or landing beam pointer is horizontal, when a glide is started and an attempt made to keep

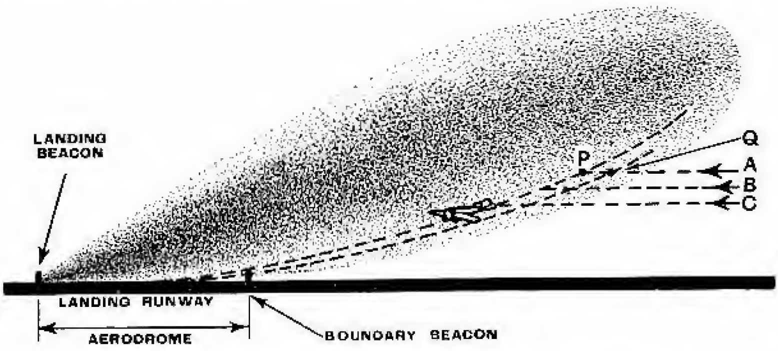


Fig. 476.—Lines of Equal Field Strength in the Landing Beam.

the two pointers in the position shown in Fig. 474(*a*). Fig. 474(*b*) shows a condition of too low and to the left, Fig. 474(*c*) too high and to the right, and to hold a large multi-engine machine on course and on the glide path introduces difficulties that are discussed in more detail later.

The wedge-shaped vertical radiation of the markers is here shown to only a few hundred feet but may be received at great heights. The beacons indicate the progress that is being made towards the runway, and on passing the boundary beacon, the height above the runway will, in theory, be known fairly accurately and will probably be of the order of 40 feet.

From practice landings with a similar type of aeroplane, the action to be taken on passing the boundary beacon and the time that will elapse before touching down will be known, but in all except extreme cases, the ground or flares will be

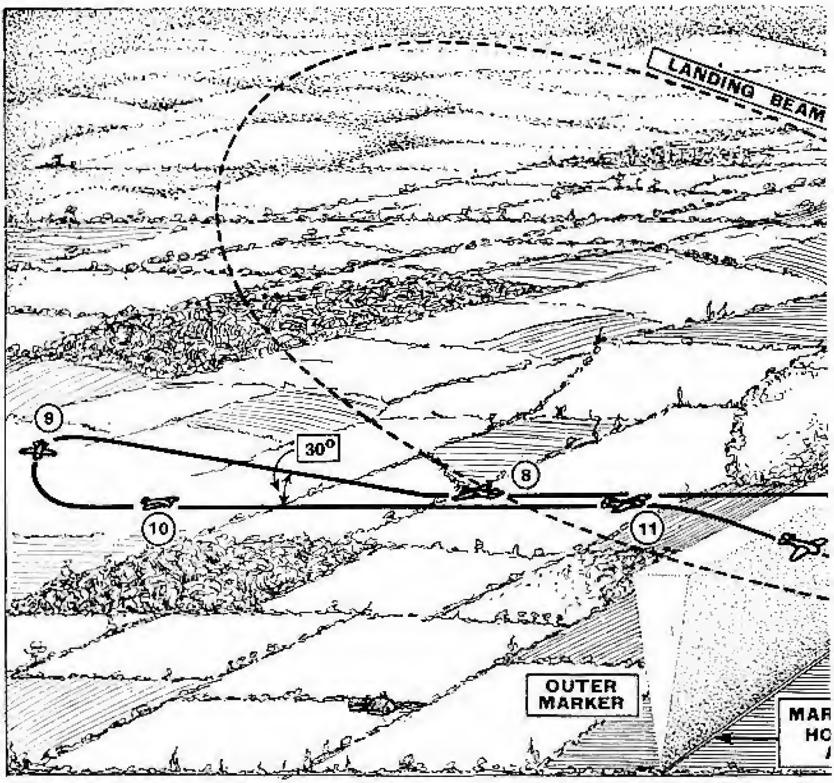
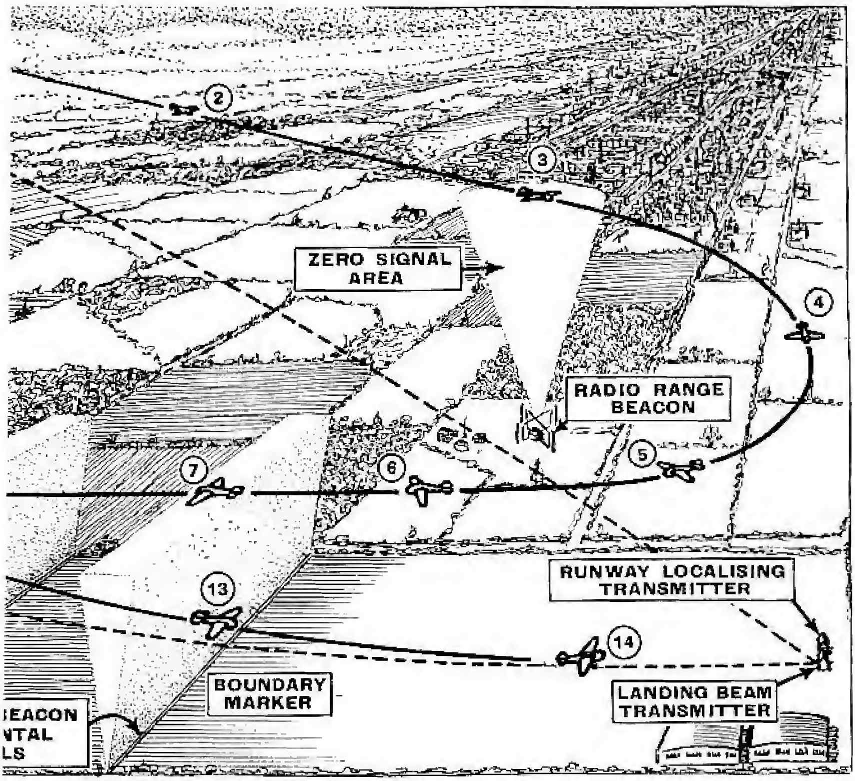


Fig. 477.—Landing by the U.S.

seen in time to make a visual landing and even 20 feet visibility has been claimed to be enough to enable an expert pilot to land a small aircraft fairly easily.

Failing any visibility at all it is more or less impossible to make a tail down landing and the ground is met at an undesirably high speed. This will probably mean that the aeroplane will leave the ground again and will also require the use of the directional gyro and wheel brakes to bring it to rest without swerving or danger of over-running.

It goes without saying that this landing system cannot be used without very considerable training, but, given an aeroplane that is light to handle, the early bewilderment usually disappears fairly rapidly when the pilot becomes familiar with the process and when the interpretation of the visual indicators becomes semi-automatic.



Bureau of Standards System.

THE LORENZ THICK WEATHER LANDING SYSTEM

The present-day arrangement of this system dates from 1932, when the use of ultra-short waves was suggested, using vertical polarization for the equi-signal lateral guidance (3210). The use of horizontal dipoles for the purpose had been considered unsatisfactory in the German experiments, owing to the disadvantage of having to use a horizontal dipole receiving aerial in the aeroplane, which led to difficulties due to its directive properties. Some account of the development up to this time will be found in (3210) and (3219) whilst later work is dealt with in (3321), (3322) and (3410).

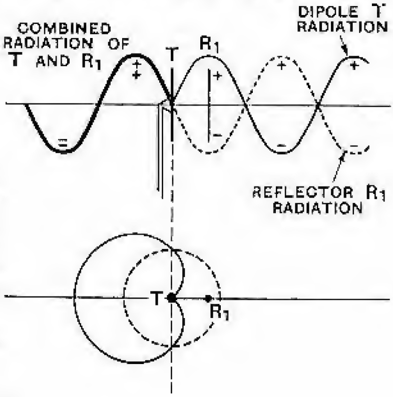
Bearing in mind the principle of the Bureau of Standards blind landing scheme already mentioned it is interesting to see how the use of ultra-short waves throughout has modified the system as developed in Europe, and how the idea of the Dunmore landing beam has been incorporated in an ingenious way in the runway localizing polar diagram. There are of course, many divergencies from the American practice as will be found in the short description of the Lorenz system that follows.

Although briefly called the " Lorenz " system, the basic principle of the combined landing and lateral guidance beams is said to be due to P. von Händel of the Deutsche Versuchsanstalt für Luftfahrt (German Research Institute for Aviation), whilst the Deutsche Reichsamt für Flugsicherung (German Board for the Protection of Aircraft) and the Deutsche Luft-Hansa were also closely associated. The Lorenz Company have manufactured the apparatus and have worked out the details of the system in its present form E. Kramar being responsible for most of the published data.

Ultra-Short Wave Approach and Landing Beacon. The aerial used for transmission is a vertical dipole, the wave length being 9 metres (33·33 Mc.), the method of obtaining the equi-signal effect being by keying suitable reflectors, whilst the aerial itself is radiating continuously.

A vertical dipole has a circular polar diagram of radiation

Fig. 478.—Radiation of Vertical Dipole with Reflector.



in the horizontal plane as shown dotted in the plan view of Fig. 478. The addition of a second vertical wire R_1, approximately $\lambda/2$ in length, near a transmitting dipole, will modify the polar diagram owing to the reflecting or re-radiating properties of R_1. The radiation from T, shown conventionally by the solid line sine curve will, on reaching R_1, induce an e.m.f. in the wire. The resulting current, the phase of which will depend upon the length and hence the " tune " of the reflector, will radiate in such a way as to tend to oppose the electromagnetic field of the transmitter T in the neighbourhood of R_1, as shown by the dotted curve.

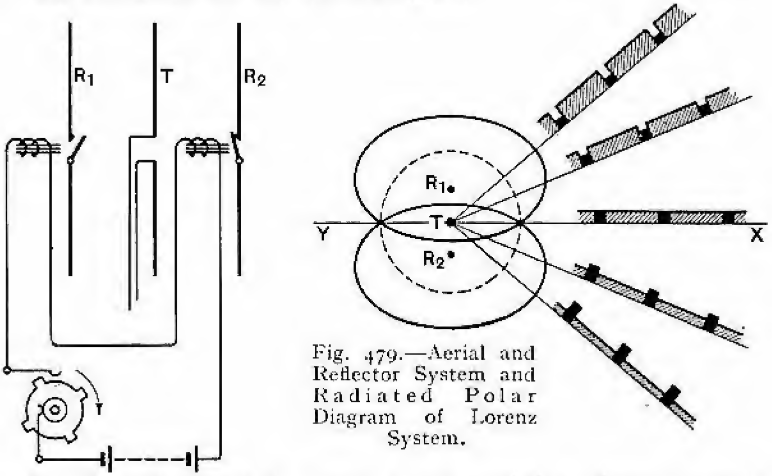


Fig. 479.—Aerial and Reflector System and Radiated Polar Diagram of Lorenz System.

In Fig. 478, T and R_1 are $\lambda/4$ apart, and the reflector current and e.m.f. are supposed to be in phase, with the result that there is no effective radiation in the direction TR_1 but there is an augmented radiation in the opposite direction R_1T, with a resultant cardioid polar curve as shown.

In the Lorenz beacon this complete cardioid effect is not used and an intermediate condition is employed as in Fig. 479, which shows both reflected and unreflected diagrams of radiation. By breaking the reflector in half with a switch, the space pattern can be rapidly converted from the circular to the reflected diagram.

In Fig. 479 a second reflector R_2 has been added, also fitted with a switch, and it is easy to see that by open-circuiting one reflector and simultaneously closing the other in an interlocked signal sequence, the radiation will be changed from one direction to the other. Along the line XY will be an equi-signal course, but having additional properties mentioned later. The modulation frequency used in this beacon is 1,150 cycles per second.

In the short interval between the opening of one reflector and the closing of the other, the transmitting dipole will be radiating alone, the circle diagram of which is shown dotted, and it is important that this circle should pass through the point of intersection of the two asymmetrical diagrams. If this does not occur, there will be momentary changes in signal intensity, or key clicks, when listening along the on-course line.

The dipole and reflectors of the main beacon are normally supported on a wooden framework as in Fig. 480 which shows the Gatwick airport installation.

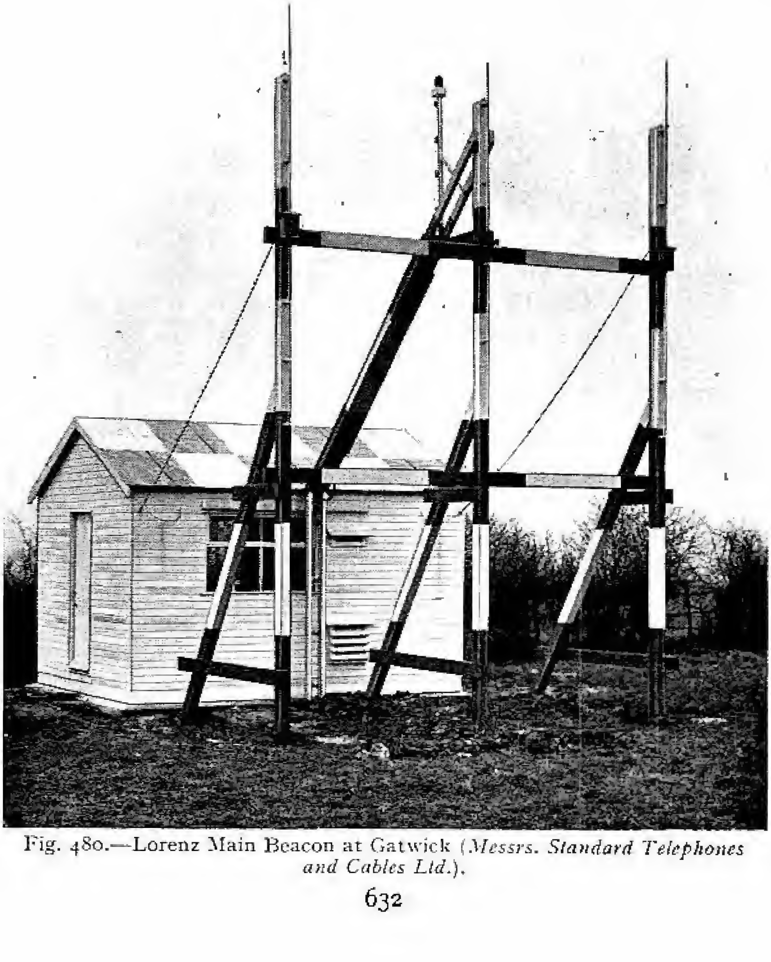


Fig. 480.—Lorenz Main Beacon at Gatwick (*Messrs. Standard Telephones and Cables Ltd.*).

The Vertical Space Pattern. The upper portion of Fig. 481 shows a cross section through the solid pattern of radiation, taken in a vertical plane through the course line XY seen in the plan view below. A few moments consideration will show that in addition to the lateral equi-signal course, there is also a series of these courses AA, BB, CC, etc., along which the signal strength remains uniform, as the beacon is approached, and which can be used in such a way as to combine in the one beacon, the functions of the runway localizing beacon and the landing beam.

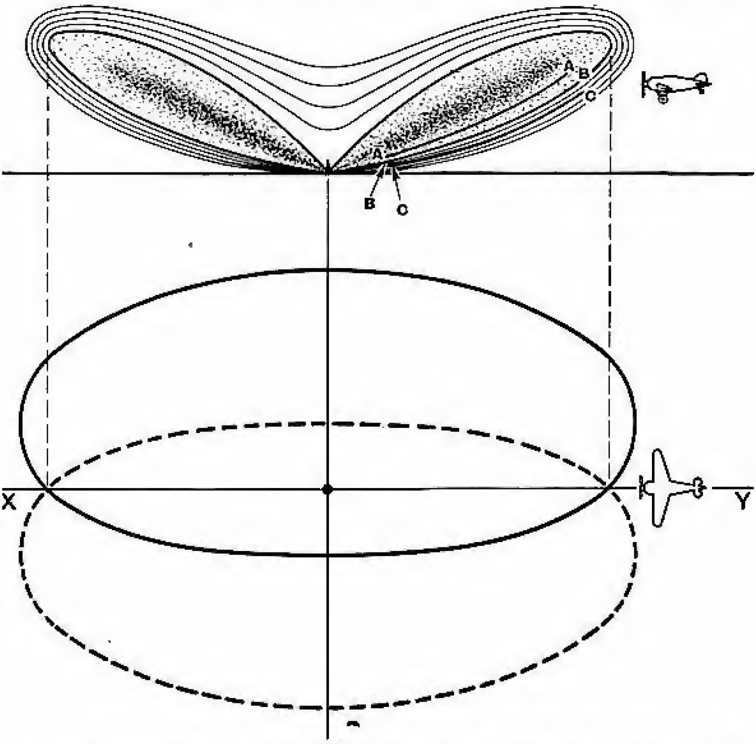


Fig. 481.—Space Patterns of Radiation from Lorenz Main Beacon in Vertical and Horizontal Planes.

Marker Signals. The first warning or marker signal, illustrated in Fig. 482 shows the point at which the glide should begin when approaching the beacon at a height above the ground of about 600 feet, and the second marker is at the aerodrome boundary.

Both the signals are transmitted on a wave length of 7·895 m.

(38·0 Mc.) but are different in character and modulation frequency. The first or outer marker consists of $\frac{4}{10}$ second dashes with $\frac{1}{10}$ second spaces on a 700 cycle note, whilst the inner or boundary beacon is a $\frac{1}{15}$ second dot with a $\frac{1}{10}$ second space on a 1,700 cycle note. The characteristics of these and the main beacon are shown in Fig. 483.

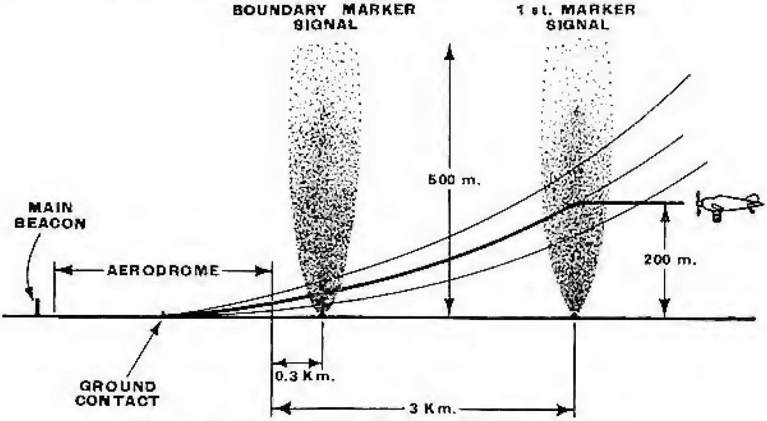


Fig. 482.—Lorenz Glide Path and Marker Beacons.

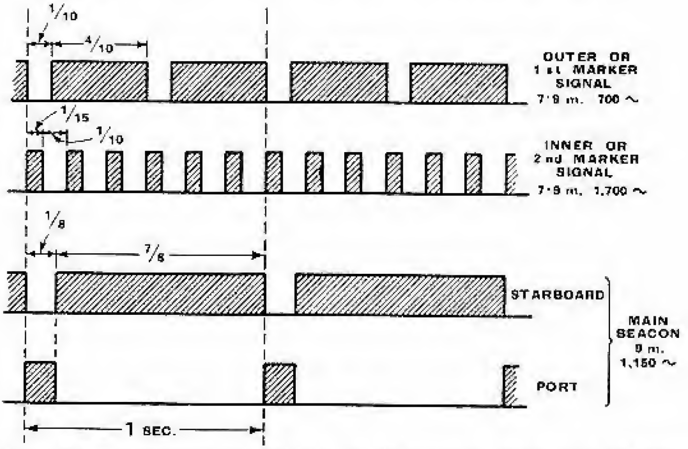

1/10
4/10
OUTER OR 1 st MARKER SIGNAL 7·9 m. 700 ~
1/15
1/10
INNER OR 2 nd MARKER SIGNAL 7·9 m. 1,700 ~
1/8
7/8
STARBOARD
PORT
MAIN BEACON 9 m. 1,150 ~
1 SEC.

Fig. 483.—Characteristic Signals of the Lorenz Main and Marker Beacons.

To make provision for an aircraft passing over the beacons at a considerable height, in its approach to the port, and desiring to locate the marker beacons, the vertical radiation provides ample field strength at heights of 1,500 feet and has a lateral width of ±1,000 feet in case the aircraft passes to the side of the approach course.

An important point also is the depth through the vertical radiation which is arranged to give a signal duration of 6 to 10 seconds.

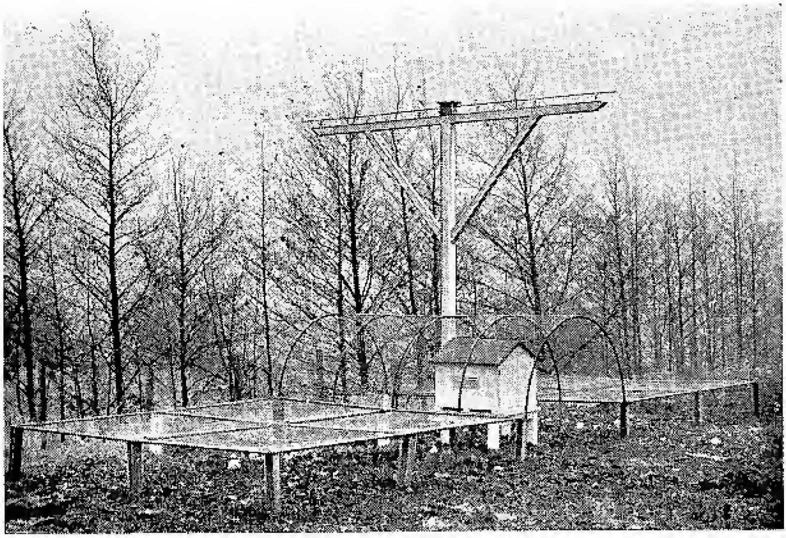


Fig. 484.—Lorenz Outer Beacon Transmitter at Gatwick Airport (*Messrs. Standard Telephones and Cables Ltd.*).

Fig. 484 shows the horizontal dipole aerial of an outer beacon (Gatwick), the aerial being at a height of about half a wave length above the reflecting net. The 5 watt transmitter is housed under the screen; it has crystal control, as in the case of the main beacon, and is remotely controlled from any desired position. The inner beacon apparatus is identical, apart from the transmission characteristics.

Receiving Aerials. A vertical rod about 80 cm. in length, mounted on or near the highest portion of the aeroplane and suitably stayed, is used for the main beacon 9 m. signal, and a dipole consisting of two wires 80 cm. long receives the 7·895 m. marker signals. Since the marker signals are horizontally polarized, the receiving dipole is secured horizontally below the body of the aeroplane but requires a spacing of only about 2 inches, even from a metal surface, so that little wind resistance is offered.

Receiver Layout and Instruments. The diagram of Fig. 485 shows how the common low-frequency amplifier serves for both the 7·895 m. and 9 m. signals, all of which are first heard in telephones, being easily identified by their notes and keying characteristics. After this follows a filter chain which passes the three note frequencies to three different indicators.

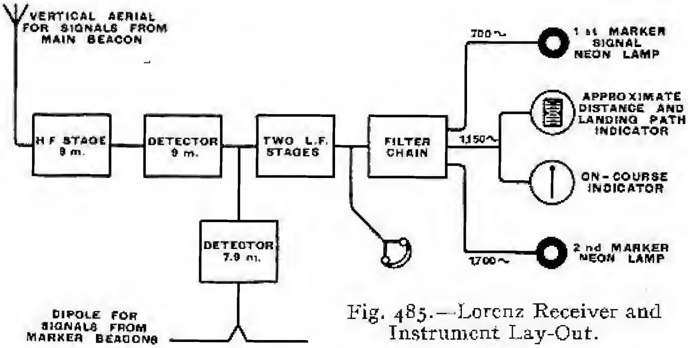

VERTICAL AERIAL FOR SIGNALS FROM MAIN BEACON
H F STAGE 9 m.
DETECTOR 9 m.
TWO L.F. STAGES
FILTER CHAIN
DETECTOR 7.9 m.
DIPOLE FOR SIGNALS FROM MARKER BEACONS
700~
1st MARKER SIGNAL NEON LAMP
APPROXIMATE DISTANCE AND LANDING PATH INDICATOR
1150~
ON-COURSE INDICATOR
1700~
2nd MARKER NEON LAMP

Fig. 485.—Lorenz Receiver and Instrument Lay-Out.

The marker signals operate neon lamps, the passage of the first marker producing dashes at half second intervals on a 700 cycle note in the phones with corresponding neon flashes, whilst the second marker is distinguished by six dots a second on 1,700 cycles with similar rapid flashing of the second neon lamp, allotted to this beacon.

The 1,150 cycle audio frequency signal of the main beacon operates two instruments, one of which is the Distance and Landing Path indicator, the deflection of which gradually increases as the main beacon is approached, being roughly calibrated in miles, and which is maintained throughout the glide at the reading shown when the first marker beacon is passed.

The second instrument is the on-course indicator, which takes account of the relative strengths of the dot/dash interlock signals, and which is mentioned below.

The combination instrument is illustrated in Fig. 486 where the two neon tubes are in gauze-shielded recesses under the letters V (Vor or Fore marker) and H (Haupt or Main marker). The vertical landing path indicator is between the neon tubes, and the lateral course indicator below.

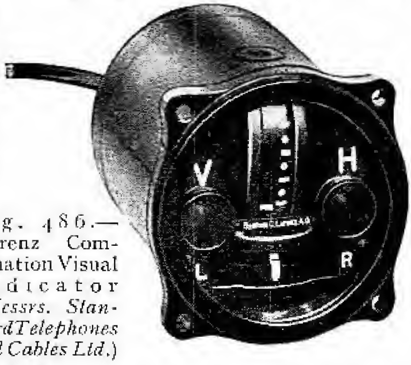


Fig. 486.—Lorenz Combination Visual Indicator (*Messrs. Standard Telephones and Cables Ltd.*)

The Dot/Dash Interlock Signal

In (3611) P. Kotowski reports on tests made with various forms of interlocked signals in order to ascertain if one could be found preferable to the A/N signal for aural use, some of the failings of this sequence having already been mentioned on page 486, in connection with the radio range beacons. The E/T and U/D sequences were compared, but the results showed that there was nothing to choose between the three.

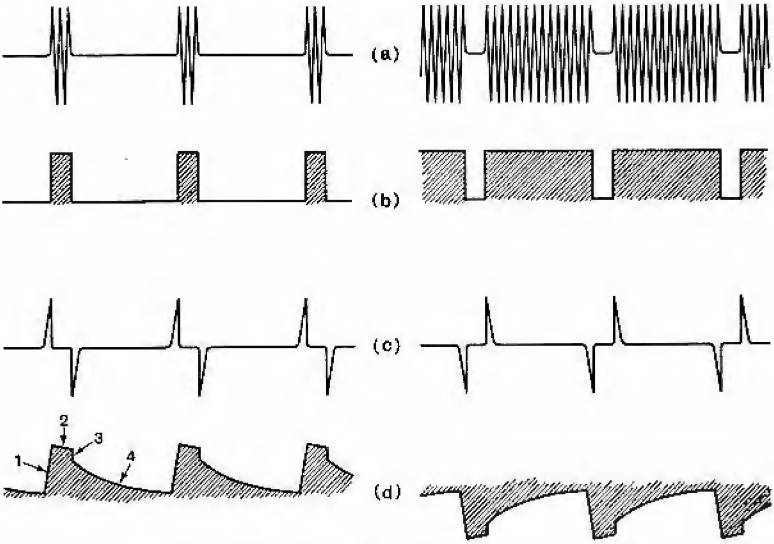


Fig. 487.—Lorenz Impulse Method of Visual Indication.

E. Kramar states (3410) that, after a long series of tests, the Dot/Dash interlock was found to be less confusing than the A/N for aural work provided that the ratio of dot to dash length was about 1 : 8 and that the duration of the dash was about a second. A point that may be somewhat troublesome when using the one-second dash is that the time constant of any associated A.V.C. circuit must be long enough to operate throughout the one-second spaces which occur when the aircraft is flying in the port side approach area. This does not occur to the same extent with the E/T in which, with normal Morse code formation, the relative lengths of the signals would be 1 : 3. (See also 3210).

An advantage of the 1 : 8 dot/dash interlock is that it makes possible the use of the simple impulse type visual indicator mentioned below.

Lorenz Impulse Method of Visual Indication

The operation of the above indicator may be followed from Fig. 487 and 488. In Fig. 487(*a*) are shown the dot and dash tone signals from the receiver output which are applied to the transformer T_1, thence to the rectifying valve V, so producing in the primary of T_2 the rectified dot and dash signals shown at (*b*). In the high ratio secondary winding of T_2 there will occur e.m.f. pulses as shown at (*c*), which will send current pulses through the meter in one direction at the beginning of each signal, and in the reverse direction at the end.

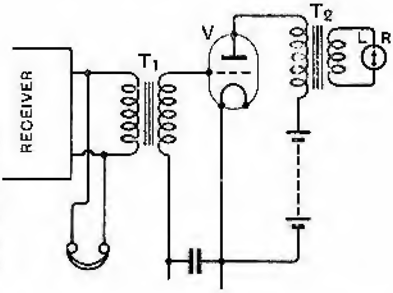


Fig. 488.—Circuit Used to Produce Impulses of Fig. 487.

In a lightly damped meter of standard design, this would produce unintelligible oscillation of the pointer. In this case the movement is strongly damped when the pointer is near the centre of the scale, whilst the magnet system is so shaped that the meter rapidly loses sensitivity as the deflection increases on either side of zero. As a result, once the meter has deflected due to a pulse, it is no longer in a sensitive position to respond appreciably to the effects of a rapidly following pulse, but is restored in time for the next signal cycle.

Due to this cause, the second of each pair of pulses is almost ineffective and the resulting pointer movements are indicated by (*d*). Here (1) is the swing of the pointer from zero, (2) is the beginning of the slow damped return, (3) is a slight acceleration of the return, due to the succeeding pulse in the opposite direction to the first, and (4) is the damped swing back.

Dots thus give a deflection to one side and dashes to the other, and the meter is connected so as to deflect towards the centre of the course. (See page 510.)

LANDING BY THE LORENZ SYSTEM

In making a landing by this system, two methods are suggested. In the first the lateral equi-signal guidance is used together with the glide path, and in the second the glide path is not used, loss of height being observed by altimeter.

Whichever method is employed, it is first necessary for the pilot to be guided to within a radius of about 20 miles of the airport by ground D.F. or homing, and he must then pick up the 9 m. beacon. Landing by the glide path method is then almost exactly the same process as that described in the case of the Bureau of Standards system on page 628, except for details of the methods of indication of the guidance and of the marker beacons which have been dealt with above.

Altimeter Method. For one or other of the technical reasons mentioned below, or because of the pilot's lack of training or his preference for the altimeter method, the u.s.w. guide path may be dispensed with. In this case, lateral guidance is obtained as before, the marker beacons still advise forward progress, but the technique of loss of height becomes that of the Hegenberger system described on page 644.

The details of a landing by the Lorenz system, using either vertical guidance or altimeter, will vary with the type of aircraft, the size and character of the aerodrome and the relative freedom of the approach sector from obstructions. The exact technique will also usually depend upon the individual pilot and is so much a part of the general problem of the handling of an aircraft in blind flight, that it cannot be pursued at length in this book.

A valuable detailed account of experiences of the Lorenz system, using altimeter, with a Monospar ST 25 aeroplane, is given by Squadron-Leader R. S. Blucke (3803).

OUTSTANDING PROBLEMS IN THE PROVISION OF VERTICAL GUIDANCE

That a satisfactory instrument method of guiding an aeroplane to the ground in fog has not yet been found is confirmed by the number of aeroplanes that employ ground co-operation when landing in poor visibility. Convincing demonstration landings in small hooded aeroplanes can be made by several systems after a short flight, and with a small percentage of failures. There is, however, a difference between this and the landing of a large passenger aircraft after a flight of several hours at high altitudes, and when the altimeter cannot perhaps be relied upon for the last 20 or even 50 feet and when the ground is so obscured by fog or snow, possibly combined with darkness, that reliance upon instruments must be complete.

This zero-zero condition is the ultimate problem for which a solution is required and widespread claims have in the past been made for the ultra short-wave landing beam in this connection—the actual blind landing being tacitly assumed if not actually included in the claim.

A fundamentally important aspect is the flying problem involved in following the lateral and vertical guidance offered. With small aeroplanes that are light to handle, the U.S.W. glide path can be fairly easily maintained after some practice, but with larger multi-engined machines that are inclined to be sluggish there is difficulty, in the ever-narrowing equi-signal course, in keeping to the glide path, since the necessary throttle adjustments alter the trim of the aircraft. Once the vertical guidance is lost the situation at once becomes dangerous as there may be scant time in which to recover.

It may therefore be of use to set down some of the imperfections of the U.S.W. glide path which are engaging attention at the present time.

The fact that the weak points of the U.S.W. glide path are being stressed is not because there is any other landing method that is perfect in the circumstances. The dangers, for instance, of any method of landing that relies purely upon an altimeter for height above the aerodrome runway, and upon the pilot's skill and judgment for the point of contact with the ground, are known well enough. During the critical moments after passing the boundary beacon, when landing by altimeter, the estimation of the proper ratio of forward speed to rate of loss of height is always difficult as it varies with barometric pressure, loading of the aircraft, the wind, if any, and other factors, so that accurate throttle control is necessary to avoid either over-running the aerodrome or the alternative of a heavy landing.

Curvature of Glide Path. One of the objections to the glide path that is produced by a line of constant field strength, as in Fig. 476 or 482, is that it is not a normal glide angle for an aeroplane as it is at no time a straight line, is liable to start too steeply, and to become too flat in the final stages.

A method of allowing departure from the line of equal field strength has been suggested by Hahnemann (Lorenz) (3321) in which, on passing the outer marker beacon, a clockwork device is started by the pilot and this, by means of a rheostat, controls the receiver gain in relation to the vertical plane. This may be designed, so it is claimed, to produce almost any desired path, allowing the optimum angle to be selected for any given aircraft and set of conditions.

This mechanism seems to have the disadvantage of including one more complexity in the ever-increasing equipment of the aircraft, and a method employed by some pilots who wish to retain a constant speed glide path, is to note the meter reading at the outer beacon and then to follow their normal glide.

This will result in an increase in the glide path meter reading as the region of higher field strength is penetrated, followed by reduction to the previous reading, and on reaching this point the original u.s.w. glide path may be followed again until the ground is seen.

In large American landing fields this last point matters less, as there is a tendency to fly in at a much flatter angle than is possible in this country where the aerodromes are smaller and where it is customary to land in a comparatively steep glide.

The difficulty is mainly brought about by the use of the vertical dipole aerial for vertical guidance. Owing to the obstruction offered by an aerial radiating a vertically polarized wave, it must be situated off the landing ground but must, at the same time, guide the aircraft to the ground soon enough after passing the aerodrome boundary to give adequate length of runway to come safely to rest.

Horizontal Polarization and Angle of Glide Path. Horizontal polarization for the landing beam has always been favoured by the Bureau of Standards in their work on this subject and a series of experiments employing a horizontal dipole in a pit, has been recently described by H. Diamond and F. W. Dunmore (3722). The pit is designed for use at the centre of the aerodrome, thus enabling a long runway to be used to full advantage, for, even with the steepest glide there remains half the aerodrome available. The use of a central beacon also contributes towards mobility to allow for varying directions of landing but presupposes a very large landing ground.

It was shown in these tests that, for the same landing point, a certain aircraft would cross the boundary with 53 feet clearance when using the centre site for the transmitter, and with only 10 feet when using the site necessitated by the vertical aerial. The flat path also has the disadvantage of leading to wide variation in the point of touching down by different types of aircraft for the reasons stated below.

Position of Contact with Ground. When it is said that an aeroplane follows a line of equal electromagnetic field strength, it must be remembered that it is the receiving aerial that is maintained on the path and not the landing wheels. Near to the ground, where the lines of field strength all converge, the discrepancy due to the height of the aerial above the bottom of the wheels becomes important since, due to the flatness of the path near the ground, the point of contact will be greatly altered.

At Newark (U.S.) Airport, the point of contact with the ground was 2,450 feet from the landing beam transmitter for an aerial height of 15 feet, corresponding to the average transport aeroplane, and was 2,000 feet for a 10 feet high aerial. A low-wing monoplane may have an aerial height of only 5 feet and in such a case the distance is reduced to about 1,400 feet.

This factor is taken into account, and in the case of aircraft with very low aerials, settling down for landing is started sooner after the boundary beacon is heard.

Stability of the Glide Path. A rather different problem is that of ensuring that the U.S.W. glide path will remain constant in varying weather and seasonal conditions. It may happen, for instance, that a glide path that is safe in wet weather when the land is almost waterlogged, may follow a much lower level and even pass below the surface of the ground when the water sinks during a dry spell.

Alternatively the glide path may be temporarily raised. In tests of the Bureau of Standards landing system mentioned in (3320), it was found that after a fall of 8 inches of snow, on which there formed a frozen crust, the landing beam was raised from 1,600 to 2,000 feet at 3 miles distant from the airport, from 175 to 205 feet at 1 mile and from 30 to 35 feet at the approach to the landing field. The effect was not noticed during other snowfalls and was ascribed to the properties of the frozen surface, nor was it dangerous in this case though it would be disconcerting to a pilot to find that the glide angle had changed.

Distortion of the radiated diagram of the landing beam due to reflection and re-radiation from tall buildings and other ground obstacles may be serious, and is likely to vary with weather conditions and even with the season when the obstacle is a group of trees. The effect is to render the paths uneven and hence confusing to the pilot who is endeavouring to hold the aircraft to an already unnatural glide angle.

Horizontal Polarization and Stability of the Glide Path. When using vertical polarization for combined lateral and vertical guidance, a vertical receiving aerial must be used, and it is important that there shall be a minimum component of horizontal electric force in the wave otherwise any lateral tilt of the aircraft will permit of reception of the horizontal component and produce errors in the equi-signal and glide paths. There should also be a minimum amount of ground reflection as this will cause the troubles mentioned above. Unfortunately, however, the reflected ray, in the case of vertically polarized radiation, is very much greater in intensity than it is for horizontal electric force.

In the experiments mentioned on page 641, with the horizontal dipole in a pit (and with which a horizontal dipole was of course used for glide path reception in the aircraft), it was endeavoured to obtain firstly as large as possible a ratio of horizontally to vertically polarized radiation to prevent discrepancies due to tilting of the receiving aerial, and to minimize the reflected ground ray, and secondly it was endeavoured to maintain the ratio constant. A critical position for the aerial was eventually found for which the ratio remained almost unaffected by the level of water in the ground surrounding the pit and which might therefore be expected to result in greater stability of the glide path.

The danger of using horizontal aerials without taking these precautions is shown by the raising of the path dne to the snow mentioned above, the 3-m. landing beam being, in that case, radiated from a horizontal array.

It may well be, however, that suitably designed horizontal arrays will give a new lease of life to the U.S.W. landing beam.

DIPOLES AND ARRAYS FOR U.S.W. APPROACH BEACONS

A disadvantage of a dipole aerial when used in a U.S.W. approach beacon is that the energy is not concentrated along the equi-signal course and the use of complex aerial arrays in order to obtain this concentration, and an easier discrimination of the equi-signal path, has proved difficult.

In most arrays, directivity is produced by the summation, with proper regard to phase, of the effects of a number of horizontal or vertical members and in some cases both types are present together. Although the polar diagram of the main beam may be found to be a smooth curve, it often happens that, in other directions, the diagram is very irregular so that, when two such arrays are combined for interlocked signal use, the main beams produce the desired track whilst the irregular back and side radiations result in a number of spurious equi-signal courses.

Again, with a combination of vertical and horizontal radiating members, the additional problem arises of course errors due to aeroplane effect. If the radiation be mainly vertically polarized, a vertical dipole receiving aerial will be used in the aircraft, but an equi-signal approach will then only be indicated so long as the aircraft flies straight and does not bank. If a weaving flight be followed along the approach course, then each time a banking turn is made, the dipole will be out of perpendicular and so in a position to receive a certain amount of horizontally polarized radiation with possible risk of reversal of the interlocked signal indication and consequent confusion as to the side of the course.

By careful design of the array and with the aid of reflector systems, these errors can be minimized and an example of a beacon aerial of this type is shown in Fig. 491.

THE "HEGENBERGER" OR U.S. ARMY AIR CORPS BLIND LANDING SYSTEM

The method of landing described below was developed at Dayton, U.S.A., by Captain A. Hegenberger, of the U.S. Air Corps and staff under the direction of the Secretary for War. The system also goes by the name of the "U.S. Department of Air Commerce System," the department having, in November, 1934, approved its use for civil aviation.

This system, whilst having the two marker beacons, differs from that of the Bureau of Standards in that there is no directive transmission from the ground, the whole of the lateral guidance being obtained by means of a radio compass (page 505) in the aeroplane, and the altitude by means of a sensitive altimeter.

For use with the radio compass there are two medium wave non-directional ground transmitters, alongside each of which is an ultra-short wave marker beacon, as shown in Fig. 489, and the method of using them is described below.

Since the aircraft, guided by radio compass, must pass directly over the marker beacons, there is no necessity for a particularly wide beam across the line of approach, and the transmitters and aerials may be mounted in small motor vans or trucks, thus adding to the mobility of the system when used for Air Corps purposes. In civil use the marker beacons would normally be permanent structures.

General Principles of the System. A general description of the system appears in the "Air Commerce Bulletin" (3424), from which the following is taken.

> "In the Army Air Corps blind landing system use is made of two small automobile truck transmitting stations of the type above described. In addition, each truck is equipped with a small secondary transmitter which, operating in conjunction with a second instrument located near the radio compass indicator on the airplane instrument board, causes a light to flash as the airplane

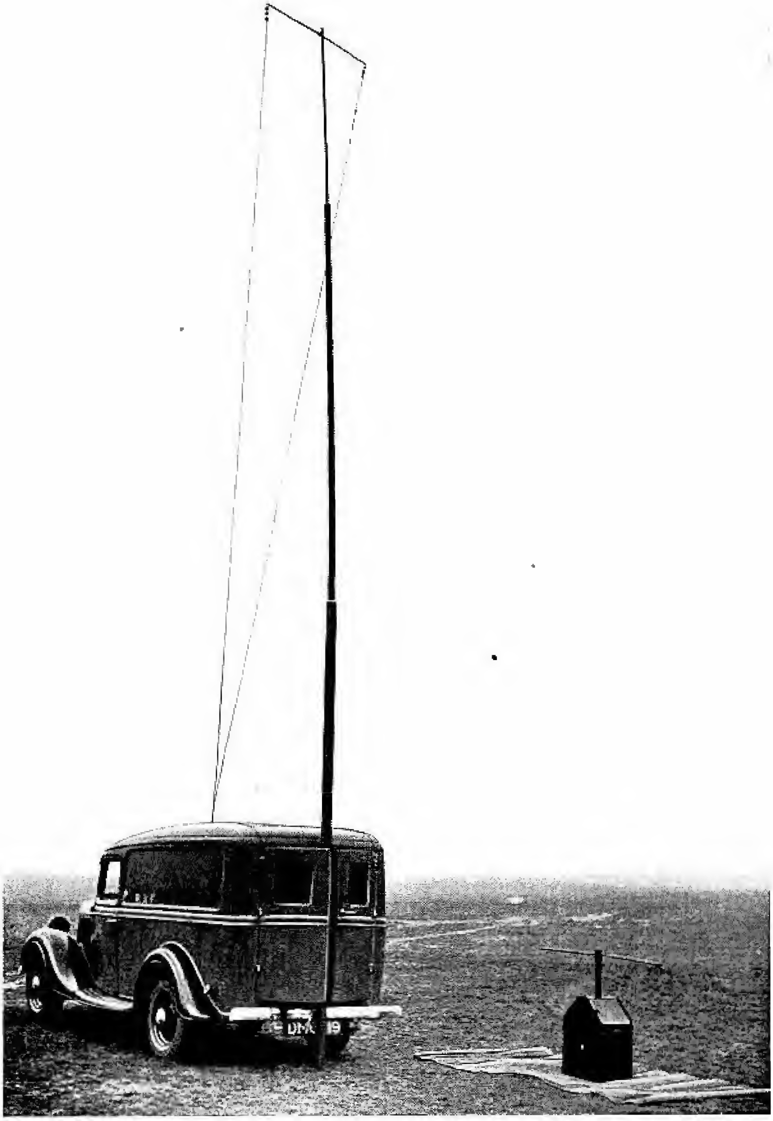


Fig. 480. Mobile Medium Wave and Ultra-Short Wave Marker Beacons for Use with Hegenberger System (*Jour. Royal Aeronautical Soc.*) (*Crown Copyright Reserved*).

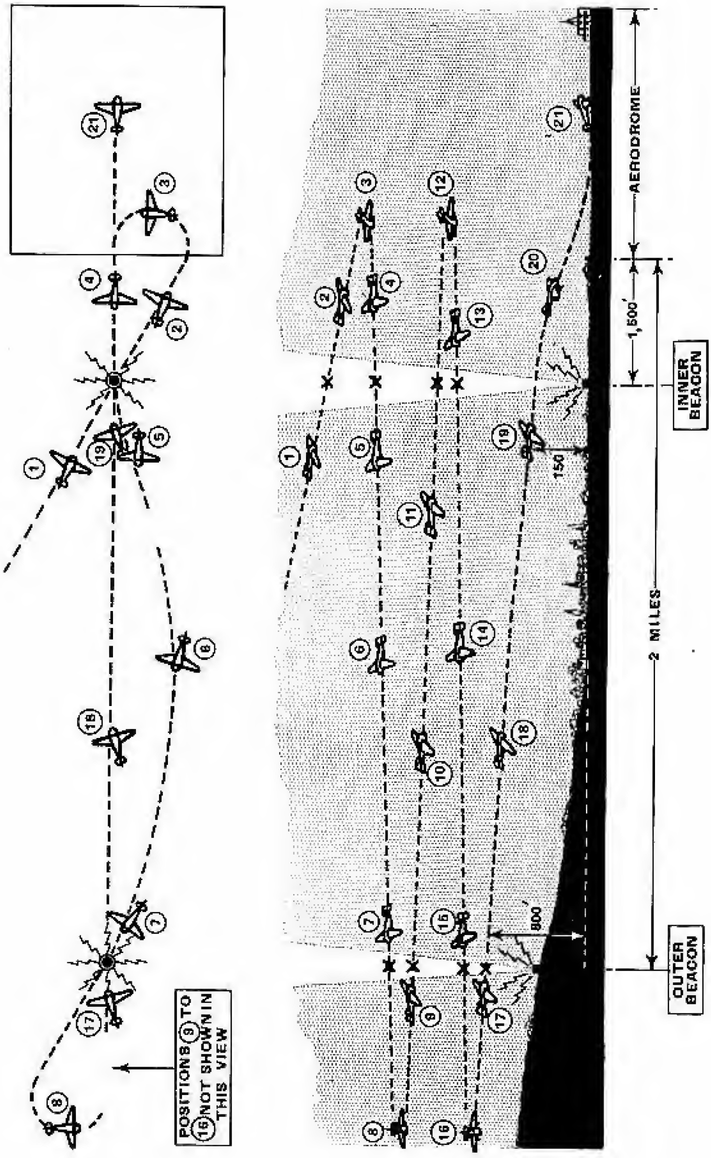


Fig. 400.—Landing with the Hegenberger System.

passes over each ground station. Thus the pilot having arrived at a predetermined point by means of the radio loop compass, is informed of his arrival by the visual marker's light flash just described.

" In actual operation the two trucks are driven to selected points on the road network surrounding the landing area, and assume positions along a line projected across the field in an into-the-wind direction. Whereas the relative distances of these positions from the field border may be varied to suit conditions of terrain, wind, etc., a convenient combination for most conditions with the Ford trimotor * is 1,500 feet and 2 miles from the field border for the inner and outer stations respectively. The pilot flying in by instrument from some distant point may, when within 30 or 40 miles, tune in on the inner station and fly directly to it by means of his radio loop compass. His momentary arrival over the inner station is indicated by the light flash of the visual marker instrument. He immediately tunes on the different frequency of the outer station and flies to it by the same means. One or more interstation trips serve to accurately establish the desired into-the-wind course, which is then clocked on the directional gyro. In preparation for the final approach, the pilot lets down to approximately 800 feet as indicated by his sensitive altimeter and heads towards the field, passing over the outer station at this altitude. Immediately on passing this station the engines are throttled and the airplane by instrument is held in a power glide of such angle as to enable it to pass over the inner station at an indicated altitude of about 150 feet. Once the final marker light flash has been received, the pilot is through with radio loop compass and marker and through with altimeter. Reverting to his directional gyro for course, he relies on his flight instruments to maintain the glide angle before mentioned. In the Ford trimotor we have found engine speed of 1,150 revolutions per minute and air speed of 75 m.p.h. producing a rate of descent of 400 feet per minute to be about the optimum desideratum. These figures are, however, by no means critical and may be varied within limits with almost equally good results. Contact is made usually lightly in a " wheel type " landing with tail slightly below line of flight position. The pilot on feeling the contact, closes

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* An aeroplane extensively used in tests on the system.

the throttles and as the tail drops of its own accord, is able to apply brakes by reference to the directional gyro or to shorten the landing run.*

Further Notes on a Landing. A landing is shown in Fig. 490, in which the successive positions of the aeroplane are shown in plan and side elevation.

Having crossed the inner beacon, turned (1, 2, 3, 4), recrossed the beacon and started homing on the outer beacon, the next three positions (5, 6, 7) show exaggerated drift, it being assumed that the bad visibility is accompanied by wind. On crossing the outer beacon, a turn is made (8, 9) that will bring the aeroplane back on to the line of approach.

A trial approach (10, 11, 12) is now made, the drift angle when found being noted on the gyro. This trial approach is not shown in the plan view of Fig. 490 to avoid confusion. The usual procedure for determining the amount of drift compensation to be allowed in the final approach is to keep the radio compass needle central during the trial approach and to note, on the gyro, the amount of the accumulated drift. The approximate drift angle is then taken as half of this value and can be checked during the return journey to the outer beacon.

The trial approach is here shown at about 1,000 feet, but might be taken down lower over the inner beacon in order to check for a change of wind velocity at the lower altitude.

Having arrived at the correct drift allowance and returned to the outer beacon (13, 14, 15), a turn is made which may be of the type described in reference to the outer beacon of the Bureau of Standards system in Fig. 477, different pilots having their own process of ensuring crossing this beacon in the proper line of approach.

In the final approach the radio compass indicator will be kept at the predetermined position and a careful watch kept on the gyro for constancy of reading. If the latter should vary by more than 5° during the final glide, the landing will generally be abandoned and another circuit made.

A somewhat different technique is described in (3803) by Squadron-Leader R. S. Blucke, in connection with a long series of experimental landings with the system in this country. This reference also contains much valuable comment on the Hegenberger system, including the original illustration here reproduced in Fig. 489.

Marker Beacons. The transmission for the marker beacon flashing signals is on the same ultra-short wave for both inner and outer beacons, and will actually operate the indicator at a height of 10,000 feet and right and left of the approach line to a distance of 3,000 feet. The distance through the vertical beam in the direction of flight is such that for a normal landing the duration of the flash is about $1\frac{1}{4}$ seconds.

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* End of quotation from Air Commerce Bulletin.

Advantages of the Hegenberger System. An advantage of this system is that, so far as additional wireless equipment is concerned in the aircraft, it necessitates only the radio compass and the ultra short-wave marker receiver, the former of which is already a part of the normal equipment of a very large number of aircraft, and the use of which for navigation is increasing.

Arising immediately out of this is the second advantage, namely, that the pilot is able to use his radio compass to fly to the airport beacon without ground assistance and is not involved in the possible difficulties of picking up and orientating himself on the equi-signal course. With the radio compass it is also a simple matter to ensure that the aircraft is directed to and not away from the desired beacon. The usual communications with the airport will of course be necessary during QBI conditions.

A third point in its favour is that the training period required is small, since the pilot is using apparatus with which he is probably familiar and which, when once installed in the aircraft, he is likely to use constantly throughout the day. In the U.S., expert pilots are said to be able to make a hooded landing after two or three hours of practice flight. Finally there is the all important factor of mobility.

Disadvantages. Against the above-mentioned points may be noted the disadvantage of any beacon system operating in the medium waveband owing to the great congestion of channels in this band and also the difficulty of reception during bad atmospherics. The constant changes of tuning may be considered a nuisance but this adjustment can be made very simple in operation.

MARCONI ULTRA-SHORT WAVE APPROACH BEACON

This beacon can hardly be designated a new or distinct system of approach and landing, since it supplies the conventional ultra-short wave lateral guidance by means of an equi-signal track and it makes no claim to vertical guidance, which is by altimeter.

The radiation pattern differs, however, from that of a dipole system in that it has concentration of energy in the direction of the main equi-signal track, this being accomplished by the use of the Marconi " Series Phase " aerial, which was originally developed for directive transmission and reception for communication purposes. It consists of an " in line " array composed of quarter wave vertical and horizontal members, arranged in the manner shown by the thick lines in Fig. 491 (*a*). The E/T interlocked sequence has been selected and a transmitting element is used for each signal, with a central vertical reflector which contains vertical loops only.

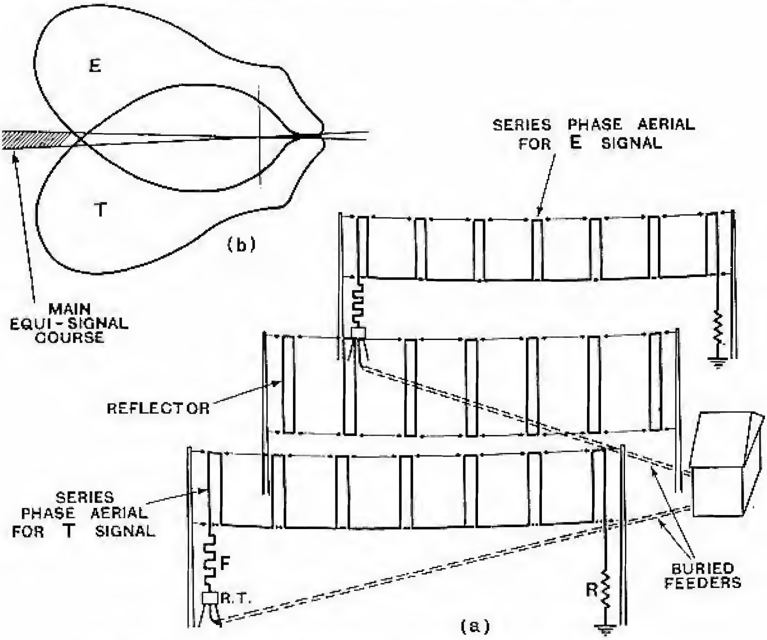

E
T
(b)
MAIN EQUI-SIGNAL COURSE
SERIES PHASE AERIAL FOR E SIGNAL
REFLECTOR
SERIES PHASE AERIAL FOR T SIGNAL
F
R.T.
R
BURIED FEEDERS
(a)

Fig. 491.—Marconi Ultra-Short Wave Approach Beacon.

Considering the near element in the diagram, power is fed by an underground transmission line to a reactance transformer RT, where the impedance of the transmission line is matched to that offered by the non-radiating feeder F. To the top of this feeder is attached the first radiating member.

At the back of the aerial is a terminating resistance R equal to the surge impedance of the element, and as a result of this there is a steady flow of energy from the transmission line along the aerial to earth through R, with attenuation due to radiation but with no standing waves (see page 173).

If the relative phases of the instantaneous currents in the vertical and horizontal members be now examined with the aid of vector diagrams, it is found that the radiation is mainly additive towards the fed end. Space does not permit further detail of the aerial as this book was in too far advanced a state when the information regarding the beacon became available. Particulars of the Series Phase aerial array are, however, given in (3616) and (3709).

As a result of the concentration of energy roughly along the equi-signal course, as shown in Fig. 491 (*b*), it is claimed that the beacon requires only one-third to one-quarter of the power needed for a dipole system of equivalent range.

The wave length used is the internationally approved wave of 9 m. (33·33 Mc.) modulated at 1,150 c.p.s. The two marker beacons also use the prescribed radio and modulation frequencies already mentioned in connection with the Lorenz system.

BAUMANN AND ETTINGER SYSTEM OF BLIND LANDING

This system differs from those already described in that the ultra-short wave transmitter is now located in the aeroplane and the lateral and glide paths are directed by the properties of ground receiving aerials. These ground signals are then retransmitted to the aeroplane on a long wave and there indicated on the conventional types of meter. The advantages claimed for the system are that, since no ultra-short wave reception is carried out in the aircraft, many of the difficulties due to ignition interference are avoided, whilst monitoring of signals by the ground staff becomes possible and they can thus watch the progress of the landing.

It might be thought that there would be no great advantage in this latter process since the speed at which the landing takes place would make it impossible for any assistance to be rendered. The important aspect is that the pilot has many things to distract him when trying to land in bad visibility and may become confused. The ground staff, on the other hand, are able to watch a set of indicators that are duplicates of those in the aircraft and can concentrate on its apparent movement, aided possibly by the sound of the engines in certain cases and can break in and telephone either advice or warning if considered necessary. Other points for and against the system will become apparent later.

In Fig. 492, A is an ultra-short wave transmitter in the aeroplane with associated dipole aerial from which a continuous signal is emitted, with modulation of a constant frequency and amplitude. This signal is received at three points on the ground, thereby indicating the lateral course, the glide path and the point at which the glide is to be started. This is done in the following manner.

Lateral Guidance. The U.S.W. signal is received on the crossed loops L which are in turn switched by the unit M to the U.S.W. receiver N. The switch is designed to connect one loop for a longer period than the other so that a dot-dash sequence is obtained, the dots being the stronger signal when the aircraft is to one side of the course and the dashes louder on the other.

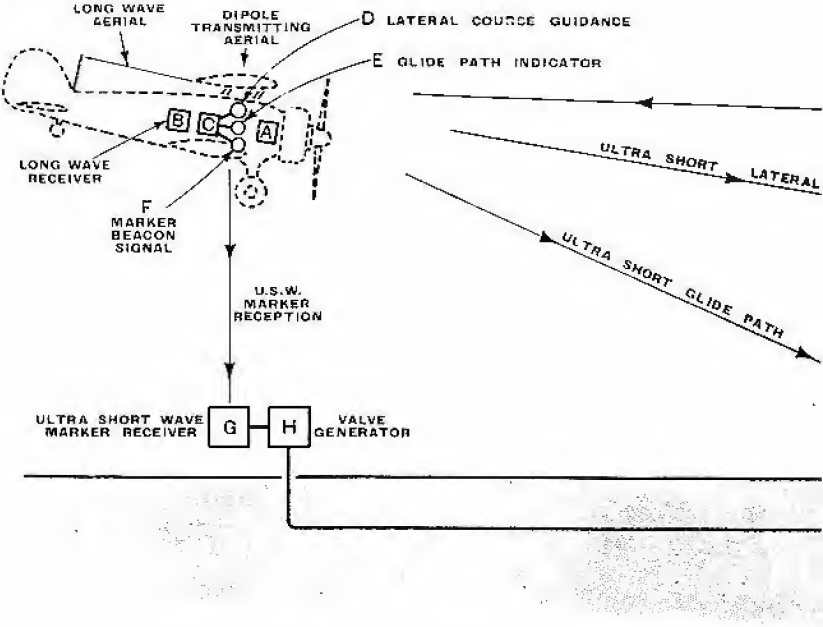
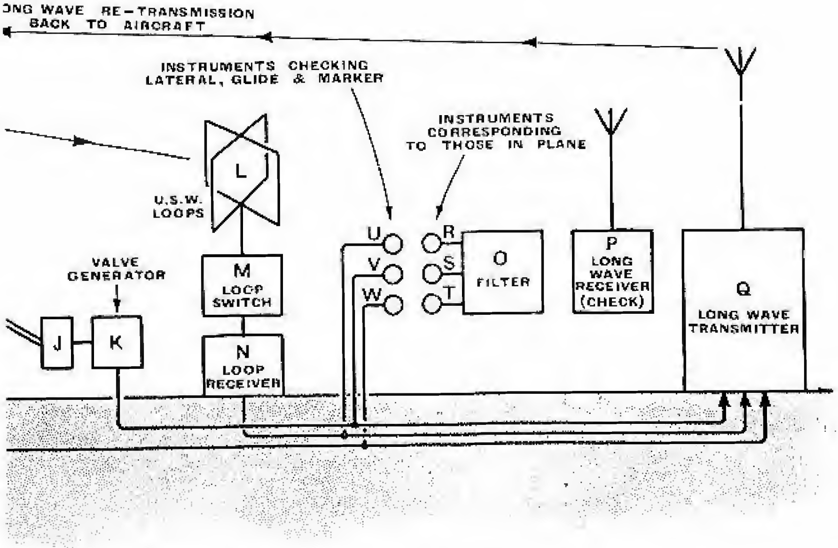


Fig. 492.—The Baumann and Ettinger Approach and Landing Syst

The modulated output from the receiver N is used to operate a visual indicator at U and is also passed to the long wave transmitter Q, operating on about 350 kc., which is picked up by the receiver B in the aircraft and diverted by the note filter C to the lateral course indicator D.

Glide Path. In the experimental model of the system (it does not appear to have been in actual use to any extent) the directive properties of a receiving dipole on the ground are used. The output of the U.S.W. receiver J is connected to a valve generator K, which supplies a distinctive modulation frequency to its output which is used to operate a glide path visual indicator at V, and also to modulate the long wave transmitter Q.

Again the received note is filtered by the network C and directed to the appropriate indicator E. As in the case of the previously described glide path indicators, a change in the height of the aircraft above the proper path will produce a variation in the strength of the modulation, and hence of the V and E meter readings. A steady reading will correspond to a contour that is a junction of both transmitting and receiving aerial space patterns.


ONG WAVE RE-TRANSMISSION BACK TO AIRCRAFT
INSTRUMENTS CHECKING LATERAL, GLIDE & MARKER
INSTRUMENTS CORRESPONDING TO THOSE IN PLANE
L
U.S.W. LOOPS
VALVE GENERATOR
M LOOP SWITCH
N LOOP RECEIVER
J
K
U
V
W
R
S
T
O FILTER
P LONG WAVE RECEIVER (CHECK)
Q LONG WAVE TRANSMITTER

Adapted from illustration in the Proc. Inst. Radio Engineers)

Marker "Beacon." At a suitable distance from the landing ground there is a receiver G with an aerial designed to have a vertically directed polar curve. As the aircraft flies through the zone above this receiver, the U.S.W. radiation is picked up and, by means of the modulated generator H, is made to operate the third of the ground indicators W. As before, the modulation is again applied to the long wave transmitter and by the filter C is directed to the third indicator F in the aircraft and this gives warning that the glide is to be begun. This indicator is in the form of a neon lamp.

Auto-Gain. As the aircraft approaches the transmitter Q, the intensity of the received carrier will steadily increase. In order that the amplitude of the received signals may depend upon the degree of modulation and not upon the carrier strength, it is therefore necessary that the receiver C should be equipped with auto-gain operating on the carrier. As in other approach systems, the carrier intensity can be used as a rough guide to the distance of the aircraft from the ground apparatus.

Check on Retransmission. In order to ensure that the received intelligence is being truthfully retransmitted, a second set of ground instruments are arranged at R, S and T for constant comparison with U, V and W, and are energized from a long wave receiver P with a filter network O, similar to the one in the aircraft. This long wave receiver checks the transmission from Q, and should reproduce exactly the indications given in the aircraft.

Further Claims for the System. The power of the U.S.W. transmitter in the aeroplane need not be high since the ground apparatus is working under favourable conditions and high-gain receiving equipment can be used. Furthermore, since the field of the long wave transmitter is very great in the neighbourhood of the landing ground, the signals received in the aircraft should be strong enough to require very simple gear, with a corresponding improvement in its reliability.

Portability is claimed for the ground equipment, in order to provide for changes in landing direction. Whilst the actual movement and re-erection of the apparatus may not offer difficulties, it is very doubtful whether a smooth and accurately located glide path could be relied upon when using a transportable dipole receiving aerial. The polar diagram of reception is presumably subject to the same distortions as is a transmitter diagram and would require careful examination in varying weather conditions for each orientation.

Another disadvantage which applies to all medium and long wave beacons is the difficulty of finding available working frequencies in an already crowded band (3602).

ZEPPELIN-TELEFUNKEN SYSTEM

With lighter-than-air craft, the location of a safe glide path to be traversed at high speed no longer occurs as a problem, and there is time to take a large number of bearings either from ground stations or from the airship during its slow navigation to a point directly over the landing ground.

A system employed for the landing of the large dirigibles of the Deutsche Zeppelin Reederei is described below briefly, and is seen to have some points in common with the Hegenberger system mentioned earlier in the chapter.

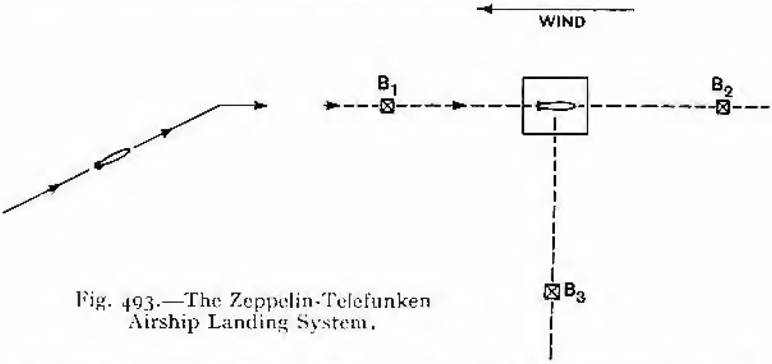


Fig. 493.—The Zeppelin-Telefunken Airship Landing System.

In Fig. 493, B_1, B_2 and B_3 are mobile transmitting beacons with omni-directional aerials, and mounted on suitable motor lorries for location round the airport in such a way that B_1 on 1093·8 m. and B_2 on 701·4 m. are in the direction of the wind, and that a line through them passes over the landing ground. The third beacon B_3 on 872·1 m. enables a fix to be obtained at the desired landing point.

Approach to the area is made by cross bearings on B_1 and any other suitable transmitters, whilst the final approach along the line through B_1 and B_2 is started from a point 10 miles from the airport.

The equipment in the airship includes three rotating loop direction finders, two of which can be seen in Fig. 401. The two D.F.'s used for the bearings on B_1 and B_2 operate pointers on a common scale, and are maintained coincident during the approach to B_1 and 180° apart during the subsequent period. The third D.F. is used to obtain a fix on B_3 when this beacon is exactly on the beam, by which time the altitude has been reduced to about 300 feet. Lines can now be lowered and the ship brought down to the ground.

Illustrations of the mobile beacons and other apparatus appear in reference (3608).

MARCONI MEDIUM WAVE EQUI-SIGNAL APPROACH BEACON

This equipment provides an equi-signal approach system from a distance of about 25 to 30 miles, together with outer and inner marker beacons, all operating on a selected wave length in the 820 to 900 m. band (365·9 to 333·3 kc.). No

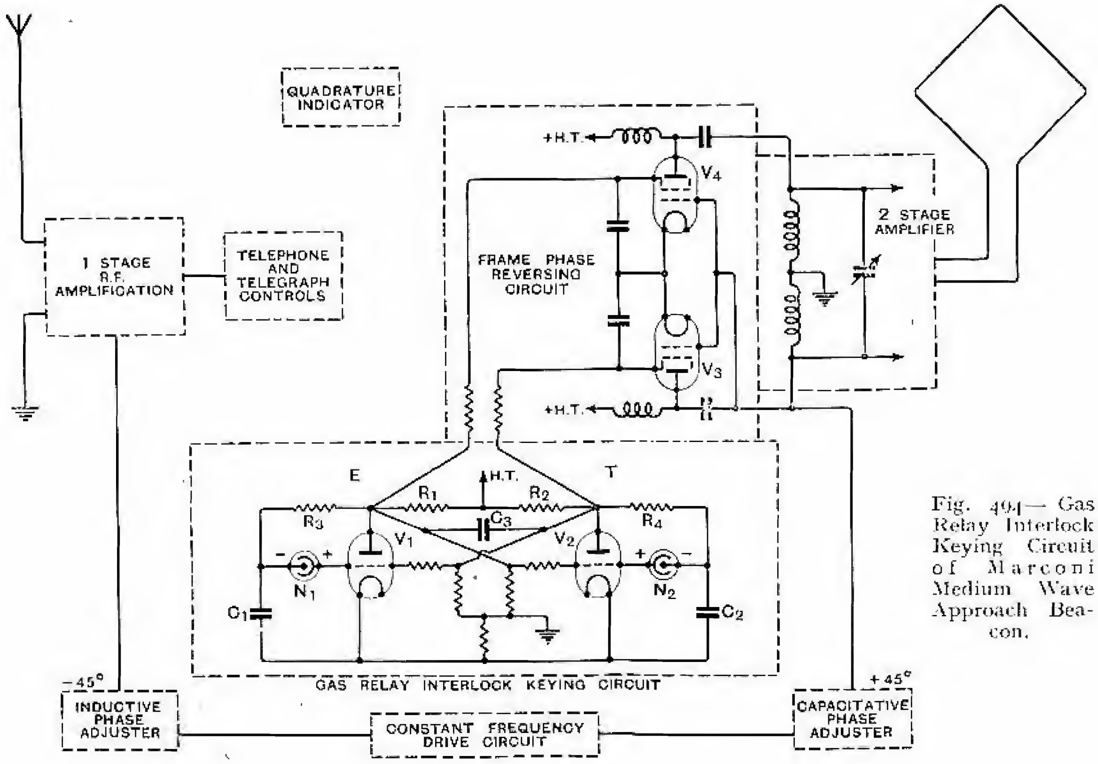

QUADRATURE INDICATOR
1 STAGE R.F. AMPLIFICATION
TELEPHONE AND TELEGRAPH CONTROLS
+H.T.
V4
FRAME PHASE REVERSING CIRCUIT
V3
+H.T.
2 STAGE AMPLIFIER
E
T
H.T.
R1
R2
R3
R4
C3
V1
V2
N1
N2
C1
C2
GAS RELAY INTERLOCK KEYING CIRCUIT
−45°
INDUCTIVE PHASE ADJUSTER
CONSTANT FREQUENCY DRIVE CIRCUIT
+45°
CAPACITATIVE PHASE ADJUSTER

Fig. 494— Gas Relay Interlock Keying Circuit of Marconi Medium Wave Approach Beacon.

vertical guidance is given, and reception can be carried out on the normal medium wave aircraft apparatus subject to the usual limitations of the trailing aerial for equi-signal use, as mentioned on page 516. Whilst there is an advantage in that no special U.-S. W. receiving apparatus is required in the aeroplane, there remain the usual difficulties due to jamming and atmospheric disturbance on the medium waveband.

The equi-signal radiation is obtained by the combination of frame and open aerial, the former being combined in alternate phases to produce switched cardioid diagrams of radiation in the way described later. The E/T interlocked switching sequence is used.

Aerials. The frame aerial, which is rigged broadside to the equi-signal line, is 230 feet long by 12 feet high and is supported on 20-foot poles. A double T-type open aerial is used, situated at the centre of the frame.

The marker beacon aerials are centre fed single straight wires, 300 feet in length, rigged transversely to the beacon line and supported 5 to 10 feet above the ground on wooden poles, to the centre one of which is attached the marker beacon transmitting unit illustrated in Fig. 496.

Main Beacon Transmitter. In the case of frame reception, the resultant e.m.f. round the loop has been seen to be a differential effect that is in quadrature with the electric force in the wave producing it. Similarly in the frame transmitter, the electric force in the transmitted wave is in quadrature with the loop current, and since the electric force in the open aerial radiation is in phase with the aerial current it will be necessary, in order that the frame and open aerial radiations shall add and subtract effectively at a distant point, that a further quadrature relation shall be maintained between the loop and open aerial currents.

A block schematic circuit arrangement is shown in Fig. 494, where the common crystal-controlled drive circuit is fed to the single stage open aerial amplifier and the two-stage loop aerial amplifier through inductive and capacitative phase adjuster units. In these units, phase changes of approximately -45° and $+45^\circ$ take place, so that the drive is actually applied to the amplifiers in quadrature. Under these conditions and subject to the aerial currents being of correct relative value, a cardioid diagram of radiation will result.

Interlock Signalling Circuit and Frame Phase Reversal. The keying circuit of the beacon and the main components have been included in a simplified diagram of this portion of the circuit in Fig. 494. It will be seen that the anode and grid circuits of the gas relays V_1 and V_2 are cross connected in such a way that the drop in potential along R_1, when V_1 is conducting, will have the effect of reducing the grid voltage on V_2. Similarly, when V_2 is conducting, V_1 will be slid back.

Between the anode of V_1 and common negative, is a time constant circuit R_3 C_1 that governs the period of non-conductivity of the valve in the following way. As soon as the V_1 grid bias is increased and V_1 ceases conducting, the potential of the anode is raised and the condenser C_1 starts to charge through the resistance R_3. The process continues, until the voltage across C_1 becomes great enough to make the neon lamp N_1 strike, whereupon the grid of V_1 receives a positive charge from C_1 and the resulting valve current causes a fall in the potential of the anode of V_1. This increases the grid bias on V_2 but, since V_1 and V_2 are gas relays, they cannot be made non-conducting by grid control alone and the condenser C_3, connected across their anodes, is used to effect the necessary anode potential drop. When V_1 is non-conducting and V_2 conducting, the V_1 side of the condenser C_3 is at high potential and the V_2 side at low potential. When V_1 conducts and its anode potential falls, the V_2 side of C_3 becomes momentarily below earth potential and so, combined with the increasing grid bias on V_2, causes this valve to cut off. The anode potential of V_2 then immediately rises and the grid of V_1 is held positive.

A similar process now takes place in the time constant circuit of V_2 and it is only necessary to adjust the R_3 C_1 and the R_4 C_2 combinations to represent the requisite time intervals, to produce any time ratio of dot to dash.

As already stated, the E/T sequence is used and the simplified diagram of the input to the two-stage loop amplifier shows how the alternate rendering of the valves V_3 and V_4 conducting, will reverse the phase of the constant frequency drive that is applied to the control grids of the valves.

It is not proposed to deal in detail with the transmitting circuits or apparatus, but the following brief account of the principal units of this installation is included in order to give a general idea of the layout of beacon equipment.

Remote Control Unit. Full control of the beacon is normally obtained at the main transmitter which is situated at the centre of the aerial system, but, in order to be able to start and stop the beacon on request, by means of apparatus in the airport control office, a unit, shown in Fig. 495, is provided and may be installed anywhere within about two miles of the main beacon.

The functions of the various components can be followed from the list given below :—

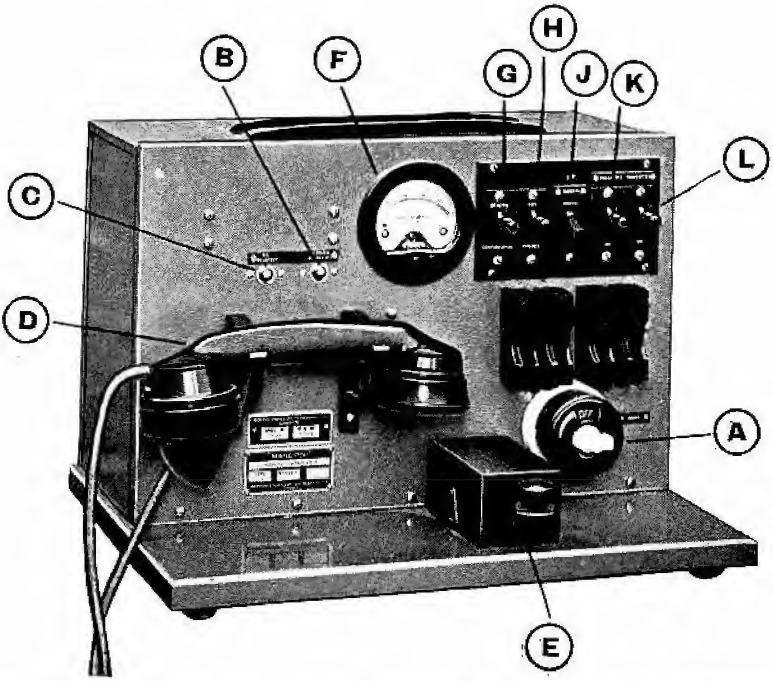


Fig. 495.—Remote Control Unit. Marconi Medium Wave Approach Beacon.

A. On-Off switch for power to unit.

B. Pilot lamp showing power on unit.

C. Pilot lamp showing D.C. supply going to line to inner marker.

D. Emergency telephone control to aircraft.

E. Emergency telegraph to aircraft.

F. Pilot meter indicating correct relative phasing of frame and open aerial.

G. Equi-Signal Beacon *or* Open Aerial Communication.

H. Telegraphy *or* Telephony.

J. Switch for D.C. supply to Outer Marker.

K. Switch for A.C. supply to Inner Marker.

L. Main Transmitter On-Off switch.

Main Beacon Transmitter. This is shown in Fig. 495(*a*), the following being the principal components and controls :—

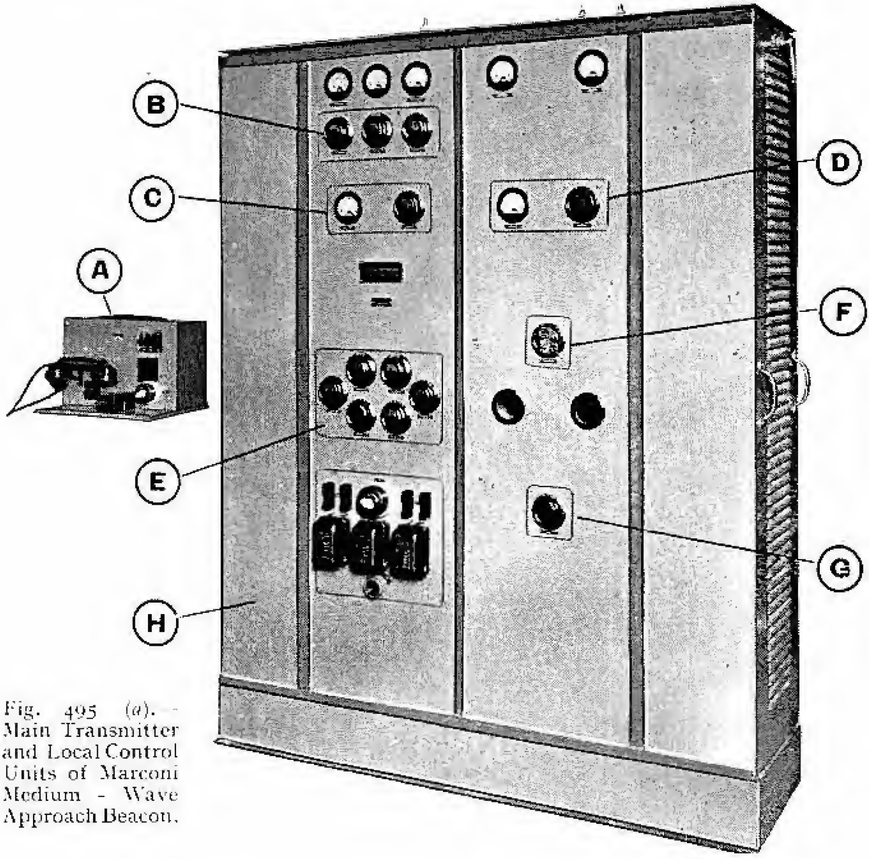


Fig. 495 (*a*).—Main Transmitter and Local Control Units of Marconi Medium - Wave Approach Beacon.

A. Local control unit, which has the same equipment as the remote control unit except that the marker beacon controls are not included.

B. Phase indicator controls.

C. Open aerial tuning and current indicator.

D. Frame aerial tuning and current indicator.

E. Amplifier tuning and phasing.

F. Frame grid circuit tuning.

G. Constant frequency drive circuit tuning.

H. Bank of rectifiers, for H.T. and Grid Negative Supplies.

Marker Beacons. A Marker Beacon transmitter is shown in Fig. 496 contained in a weatherproof case for outdoor mounting. Each of these beacons has a self-oscillator circuit together with a rotary condenser A, which normally varies the frequency ±2 kc. at speeds of 1½ times per second for the outer and five times per second for the inner marker. This radiation, by interference with the main beacon signal, produces warbling notes in the telephones. Alternative warble characteristics can be produced according to requirements.

The rotary condenser is gear-driven from a synchronous A.C. clock movement, the gearing differing in each beacon. The only other way in which the markers differ from one another is that, whilst the inner one has power supplied from the control office, the other one uses local power supply and is switched on by relay from the control room.

The remaining components are as follows :—

B. Aerial current meter.
C. Aerial coupling.
D. Aerial tuning inductance.
E. Motor on/off.
F. Total feed of valves.
G. Mains on/off.
H and J. Closed-circuit fine tuning.

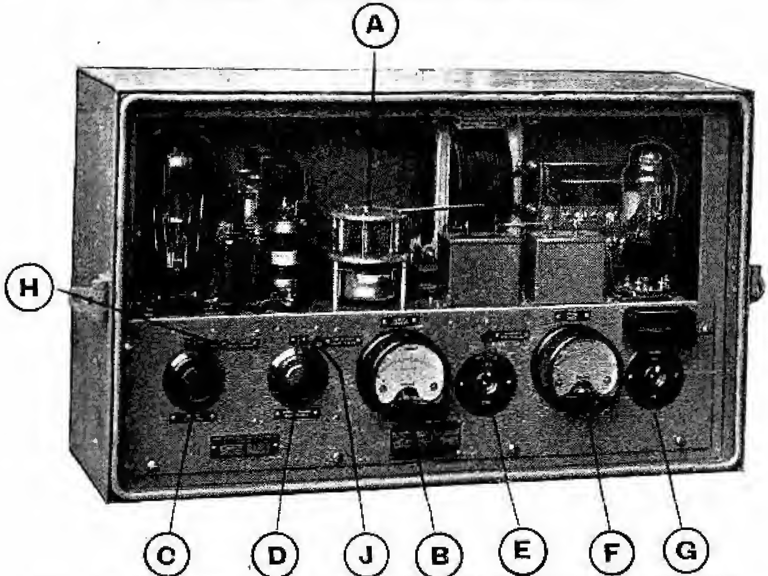


Fig. 496.—Marker Beacon Transmitter of Marconi Medium-Wave Approach Beacon.

Both marker and main transmitters signal back that they are in operation by means of radio frequency pick-up circuits arranged to transmit D.C. signals that operate pilot lamps.

CHAPTER 16

SURVEY OF OTHER D.F. SYSTEMS INCLUDING DIRECT READING PROCESSES

Introduction. In this chapter are included less conventional systems of direction finding, or accessories for use with systems already described, some of which are of such obvious importance that their extension to commercial use is only being somewhat delayed by the difficulties of perfecting a new technique, or possibly due to excessive cost. Other systems mentioned show less promise of commercial application but are included on account of their technical interest.

Direct Reading or Automatic Systems. As might be expected, much ingenuity has been expended on methods of avoiding the combined aural and manual processes of operating D.F. apparatus.

When a bearing is taken on a manual type of gear, there are three operations that must be carried out :—

(1). The loop must be rotated.

(2). A certain signal condition must be observed, associated with a special position of the loop.

(3). The scale reading of the pointer must be noted when the loop is in the above mentioned position.

In the first stage towards an automatic system, all that is done is to substitute, for the aural method of observing the signal condition, either an optical or an "instrument" method. For instance, the signal maximum or minimum may be shown by the brilliancy of a neon tube or by the reading of a centre zero milliammeter or dynamometer. In either case, the loop must still be turned independently and the bearing noted on a scale, so that neither method is any more a direct reading or automatic one than if telephones were used, although the title is sometimes incorrectly applied in such cases.

Applications of the instrument method of indication have already been described in Chapters 12, 13 and 15.

The final stage of the truly automatic D.F. is one in which it is only necessary to tune the signal from the required transmitter on the receiving equipment, and the true or relative bearing is forthwith indicated without further operation.

Classification. It is not easy to group the various forms of direct reading D.F. in any rigid classification as, in the course of their development, several of them have incorporated principles common to others of somewhat different type, and no form of mutually exclusive grouping can well be found.

Where grouping has been attempted at all in this chapter, therefore, it is somewhat arbitrary, being governed in some cases by the type of indicator used—as, for instance, the Cathode Ray Tube, which includes both automatic and non-automatic systems—and in other cases by the circuit principle used.

THE CATHODE RAY DIRECTION FINDER

There are several ways in which the cathode ray tube may be applied to direction finding, the first-mentioned below being a direct reading system and the others merely visual methods of noting a certain signal condition that indicates the required bearing, and which still involve the manual operation of the loop or radiogoniometer search coil.

Radiogoniometer. The tube may be used as a radiogoniometer, as already mentioned on page 147, in combination with either B-T or Adcock aerials. In this case, the bearing is shown by the radial position of the image on the fluorescent screen, which has a suitable scale engraved on it.

Pulse D.F. This has been mentioned on page 223, its object being the elimination, under suitable conditions, of polarization error.

Visual Pattern Indicators. Here the tube is used simply as an alternative to aural or instrument indication of the desired bearing, the image being arranged to produce patterns that vary rapidly in shape for loop and pointer movements near to the required direction. A certain easily distinguishable pattern having been obtained, the scale reading is noted in the conventional way.

Similarly, in the case of aircraft homing equipment, the shape of the pattern indicates the on-course or off-course conditions.

Some of these ways of using the tube have already had important application, and for the benefit of the reader, who is not acquainted with the principles of the cathode ray tube, the following short introduction is given.

The Cathode Ray Tube is an application of the property of fluorescence, possessed by a number of substances under the influence of electron bombardment. A beam of electrons focused on a screen of fluorescent material produces at its point of impact a luminous spot, of which the colour and intensity depend on the particular material and on the speed and number of the electrons in the beam. The materials now available provide a large range of fluorescent colours, and it is also possible to obtain "afterglow" effects of duration of a small fraction of a second up to several seconds.

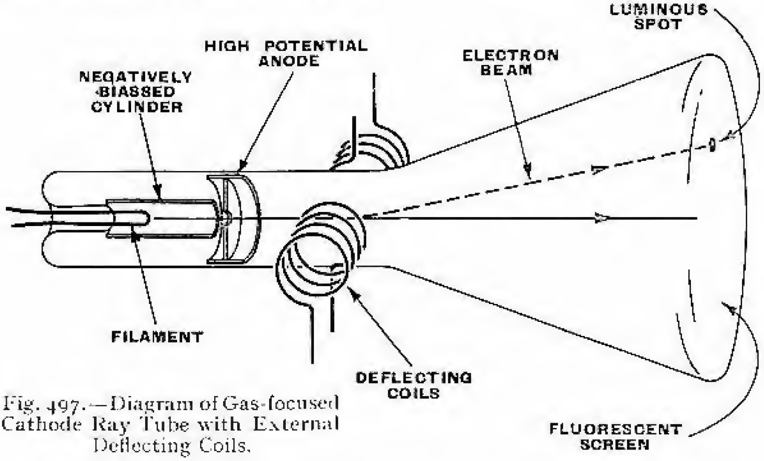


Fig. 497.—Diagram of Gas-focused Cathode Ray Tube with External Deflecting Coils.

An electron beam, consisting of electric charges in motion, can be deflected both by electrostatic and by electromagnetic forces, so that if deflecting forces are applied at one end of the beam, its opposite end traces out a visible pattern on a suitably placed fluorescent screen. The nature of the pattern is dependent on the deflecting forces, and the great utility of the cathode ray tube resides in the almost completely inertialess behaviour of an electron beam towards these forces.

Where current variations are to be examined, electromagnetic deflection is often preferable, and this is achieved by the use of coils external to the tube, as in Fig. 497. For voltage variations, electrostatic deflection is usually best, and is achieved by the use of flat plates mounted inside the tube. The latter method covers most of the requirements met in practice, and hence most tubes possess an internal deflecting system of two pairs of flat parallel plates, the two pairs being mutually at right angles.

For accurate examination of deflecting forces, the electron beam must be narrow and sharply focused on the screen. The production of such a beam is the work of the so called "gun." In general, we may broadly distinguish between two sorts of gun, the first being that in which focusing is partly electrostatic and partly due to gas, and which is used in what are known as "gas-focused" tubes or "soft" tubes. In the second type, focusing is entirely electrostatic and these tubes are referred to as "hard" or "high-vacuum." A variety of hard tube using magnetic focusing has special applications, but need not concern us here.

In gas-focused tubes, the gun consists of a localized electron source (*e.g.* an oxide coated cathode), a surrounding cylinder known as the Wehnelt Cylinder, and a flat disc-shaped anode with a central circular aperture opposite the cathode, as seen in Fig. 498. The cylinder is usually a few volts negative and the anode several hundred volts positive, with respect to the cathode. Such an arrangement produces, in vacuo, a beam of electrons of good intensity, but slightly divergent. To give the convergence necessary for a sharp focus at the screen, a rare

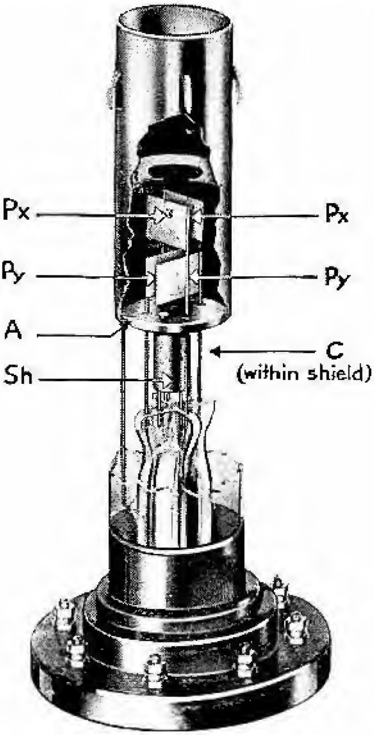


Fig. 498.—Components of Gas-focused Cathode Ray Tube.

C	Hot Cathode or Filament.
Sh	Wehnelt Cylinder or Shield.
A	Anode.
PyPy PxPx	Deflecting Plates.

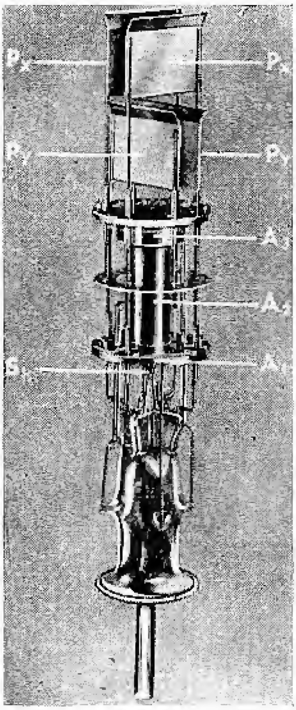


Fig. 499.—Components of High Vacuum Cathode Ray Tube Showing Three Anodes A_1, A_2 and A_3.

gas (Argon or Helium) is introduced to a pressure of about 0·001 mm. of mercury. The ionization produced by electron collision provides a central core of positive ions which produces an inward radial force on the electrons in the beam, and hence produces the required convergence. Focusing is dependent not only on the cylinder and anode voltages, but on the thermionic current, and hence adjustment to an appropriate value of the cathode temperature is necessary.

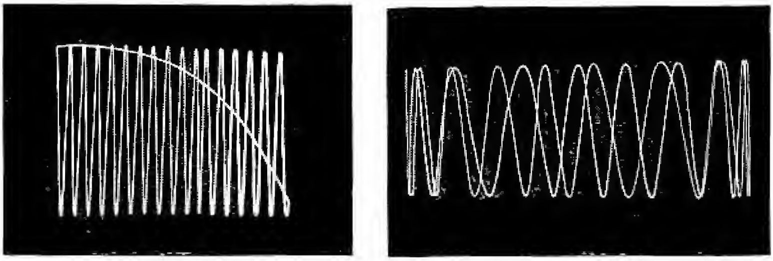
In its modern commercial form, the electrode arrangement just described is completed by the addition of a wide-diameter cylinder in the neck of the tube, surrounding the deflector plates and connected to the anode. Its function is to receive, at the expense of the deflector plates, most of the return current from the fluorescent screen, and in this way a minimum load is placed on the deflection system. This may also be seen in Fig. 498.

In high-vacuum tubes, the principles of electron optics are applied to produce a high-intensity sharply focused beam without the use of gas. A beam of electrons moving through a system of potential fields behaves analagously to a beam of light moving through a system of lenses, and by a suitable combination of apertures, cylinders and stops, an initially divergent electron beam can be made convergent and so focused. The gun is structurally more complicated, requiring usually two and often three anodes, and the deflection system must fulfil more exacting requirements, but otherwise the general design remains as for a gas-focused tube. An example of a hard tube, showing three anodes, is given in Fig. 499.

Both types of tube are now well established, and there is a field for each. In general, gas tubes have the advantage of sharp focus at low voltages, whilst hard tubes need higher voltages. On the other hand, gas tubes are not satisfactory with deflecting voltages of frequencies higher than a few hundred kilocycles, whereas hard tubes are satisfactory in all normal high-frequency work. Regarding distortion, gas tubes show pattern distortion when the deflecting voltages are small (origin distortion) and hard tubes show spot distortion with high deflecting voltages, particularly when the latter are not applied in push-pull with respect to the anode. Finally, the proper performance of gas tubes is dependent on cathode temperature and their life is limited by the cathode bombardment due to positive ions. The hard tube is free from these limitations. Lower initial cost and simplicity of operation favour the gas tube, but the hard tube is paramount in the field of high-frequency measurement.

The Time Base is the apparatus used to control the horizontal movement of the beam. It is customary to equip a laboratory oscillograph with a linear time base, that is to say, one in which the spot moves across the screen at a constant controlled speed and then " flies " back to the starting point very rapidly. The strokes succeed one another at regular intervals and their frequency can be adjusted from zero to many megacycles per second.

Sinusoidal and other forms of time bases are used for special purposes, whilst the cathode ray radiogoniometer requires no time base, as each pair of plates is associated with an aerial. When used in this way, the tube becomes a form of **comparator.**



(*a*) (*b*)

Fig. 500.—(*a*) Linear Time Base Image. (*b*) Sinusoidal Time Base Image.

In Fig. 500 (*a*), is shown the image produced by an A.C. voltage of 850 c.p.s. applied to the plates producing vertical movement of the spot, the linear time base being adjusted to 50 c.p.s. If the whole of each cycle of the time base movement could be allotted to the useful stroke, the image would include $\frac{850}{50}=17$ complete cycles. Time is, however, required for the fly-back and in the figure this is seen to take up about nine-tenths of half a period at 850 c.p.s., which is equivalent to about half a millisecond.

A sinusoidal 50 c.p.s. time base was used in Fig. 500 (*b*) and here the 17 complete cycles of the vertical movement are not distorted by a fly-back but the image has the disadvantage of being congested at both ends of each stroke and also is confused by the criss-cross effect of the symmetrical forward and backward movement.

This short introduction has served to mention some of the terms met with in connection with the use of the apparatus in D.F. work, but it is extremely superficial and the reader should refer to a text book for detailed information.

A CATHODE RAY DIRECT READING RADIOGONIOMETER

An early form of direct reading cathode ray D.F., of the radiogoniometer type, is shown in Fig. 501. The apparatus was produced by the Radio Research Board (R. A. Watson Watt and J. F. Herd), and is described in (2607), from which the illustration is reproduced.

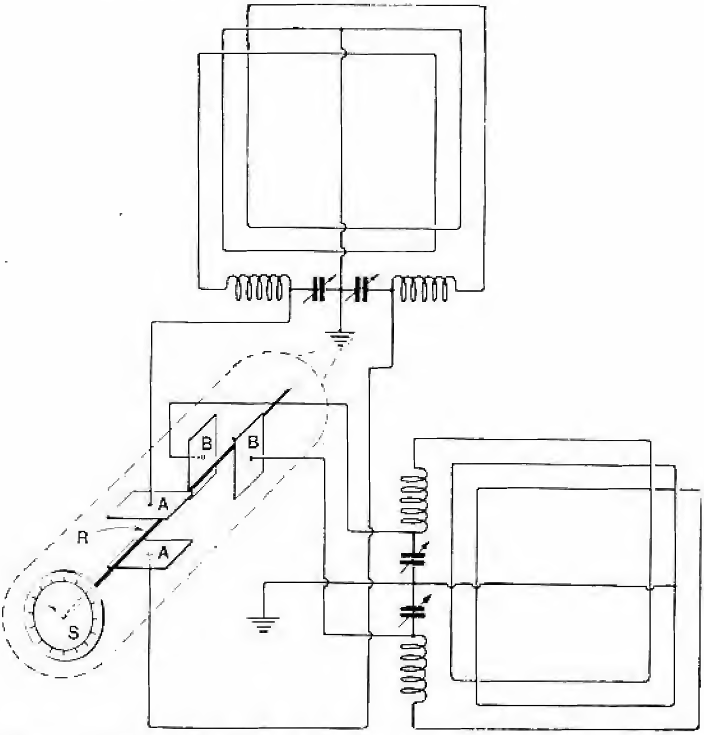


Fig. 501.—Cathode Ray Direct Reading Radiogoniometer (Jour. I.E.E.).

Two multi-turn B-T loops are connected respectively to the two sets of deflecting plates, A A and B B, of the oscillograph, and, from what has been said regarding the action of the inductive radiogoniometer, it is not difficult to see that, in this case, when the plates are equal in size and symmetrically disposed with reference to the undisturbed path of the ray R down the axis of the tube, the electric forces on the electron beam between the plates will be proportional to the e.m.f.'s in their respective loops. The movement of the spot of light on the screen S will thus be proportional, in direction and amplitude, to the direction and field strength of the incident wave.

In its experimental form, the five-turn loops required for the successful working of the apparatus were very large, being 1,200 feet in horizontal length and some 150 feet high, the total area turns being 20 acres. The large loops were used to reduce the gain required, as it will be realised that separate amplifiers were required for each loop, and it was very important that their gains should be exactly equal, and also that the phases of the loop e.m.f.'s should be maintained in the same relation throughout. The need for this will be remembered in the case of the tuned B-T system, and the cathode ray D.F. is a tuned B-T with the radiogoniometer—represented by the tube—at the end of the amplifiers instead of at the beginning. The two-stage push-pull resistance capacity amplifiers actually used are not shown in the diagram.

Effect of Amplitude and Phase Distortion. The effect of unequal gain will clearly be just the same as that due to unequal loops. The result of a phase change is rather less straightforward in the case of the cathode ray radiogoniometer, but is interesting as it forms visually a parallel to the indefinite aural minimum already encountered in the tuned B-T system due to incorrect phasing.

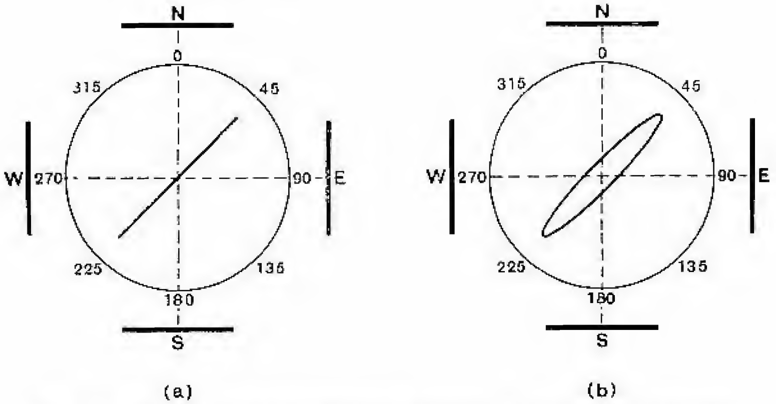


Fig. 502.—Phase Distortion of Image of Cathode Ray Radiogoniometer.

Fig. 502 represents the screen and the dotted lines N.-S. and E.-W. are drawn through the centre lines of the deflecting plates and hence represent the paths of the spot for bearings in the directions of the planes of the loops. If a signal be arriving from the North-East there will be equal signals in both loops

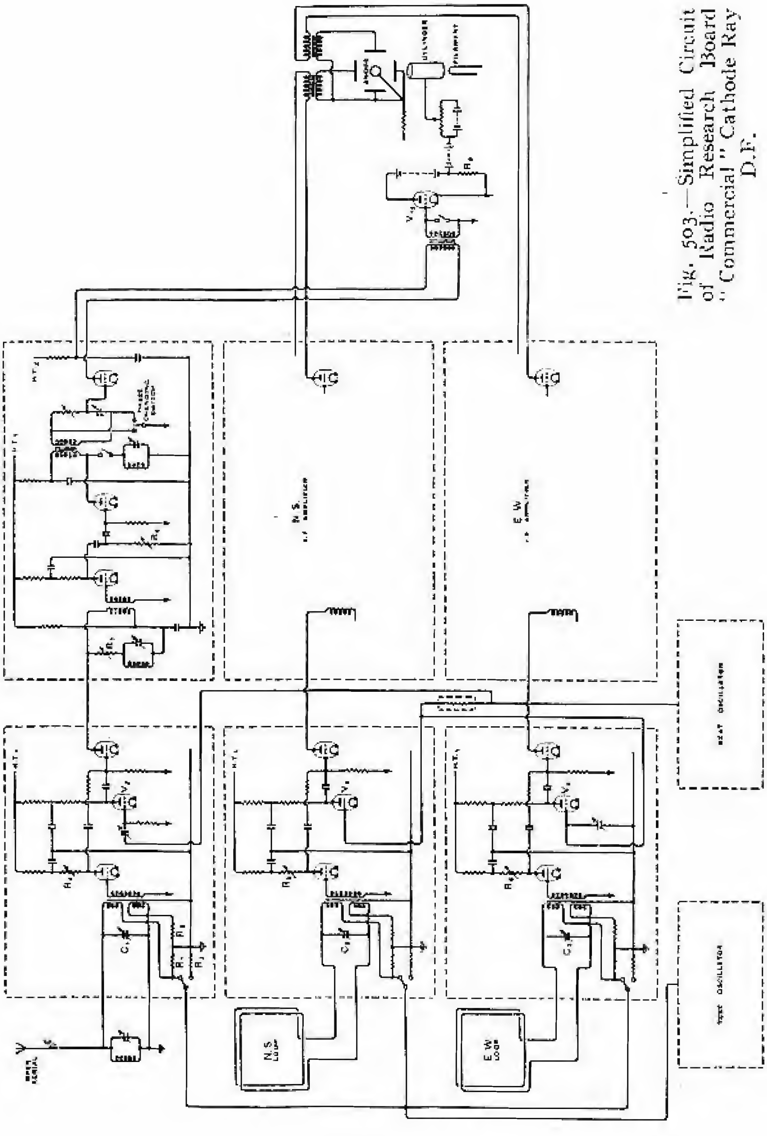


Fig. 503.—Simplified Circuit of Radio Research Board "Commercial" Cathode Ray D.F.

and hence equal potential differences between each pair of plates. Provided that the phases are also correct, the path of the spot will be along the 45°-225° bearing as shown in Fig. 502 (*a*). Any mis-phasing will produce a rotating field between the plates, and the spot will trace out an ellipse as in Fig. 502 (*b*), the major axis of which will indicate the correct bearing, subject to there being no other sources of error.

Further Development. With the improvement in amplifier technique and with the experience gained on the above apparatus, several other forms of cathode ray D.F. were produced by the Radio Research Board, the sizes of the loops being reduced to dimensions that enabled them to be housed indoors in certain instances, the apparatus employing correspondingly higher gain in the form both of straight radio frequency and superheterodyne amplifiers. A model using an intermediate frequency, and rack-mounted suitable for commercial use, is described briefly below, together with a simplified circuit diagram.*

Radio Research Board "Commercial" Cathode Ray D.F. The circuit of Fig. 503 shows the essential features of this D.F. but is not complete in detail. It consists of three almost identical superheterodyne receivers having a common beat oscillator. The lower two are associated with the two frames, and their outputs are taken to the pairs of deflector plates, whilst the top amplifier is connected to an open aerial for sense determination by methods described later.

The two variables, tuning and gain control, are carefully provided for. Due to the superheterodyne principle, the only tuning required is in the aerial loops themselves by the condensers C_1, C_2, C_3, which are not ganged, but are calibrated to read alike, and the input circuit of the open aerial has been made similar to the frame inputs for this purpose.

The gain control comprises a total of 80 db. (10,000 : 1 voltage gain) of which 30 db. is in the R.F. stage and 50 db. in the intermediate-frequency amplifier. In each case this is obtained by the use of calibrated variable resistances with special stud contacts, and in the R.F. stage it takes the form of variable anode resistances R_4, R_5 and R_6 which vary the gain of the stage. This method avoids the "jump over" that might occur if full amplification were retained and an attenuator inserted, which would be dangerous at this early stage of the amplification. The 50 db. control in the I.F. amplifier is obtained by the use of a variable resistance R_8 in the open aerial amplifier, and is similar in the two others.

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* Adapted from "The Cathode Ray Oscillograph in Radio Research," see Reference (2803), by kind permission of The Controller of H.M. Stationery Office.

Phase Adjustment. Owing to the 90° phase difference between the loop and open aerial e.m.f.'s it is necessary to introduce a 90° phase change somewhere in the aerial circuits, to obtain the correct relation for sense indication, as the frame and open aerial effects would otherwise be in quadrature. This raises a difficulty with regard to the beat oscillator, the frequency of which must, of course, differ from that of the signal frequency by an amount equal to the intermediate frequency and may be either higher or lower than the signal frequency. It is found that if the phase change is made before the introduction of the beat signal, the sense indication becomes reversed according to whether the oscillator frequency is above or below that of the signal. Accordingly the phase change is ingeniously applied to the beat signal input itself, as shown in Fig. 504, in which the beat e.m.f. is fed to the three valves V_2, V_4 and V_6 by resistance condenser systems. This arrangement produces a 45° phase advance in both frame circuits due to the parallel condenser connection, and a 45° phase retardation in the open aerial circuit due to the series condenser, these amounts being fairly exact at mid-range and effective over the whole tuning range.

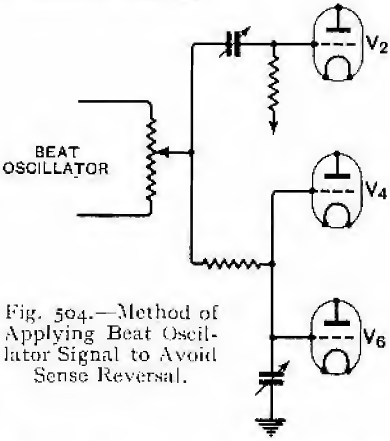


Fig. 504.—Method of Applying Beat Oscillator Signal to Avoid Sense Reversal.

Sense Determination. In the description of the cathode ray tube on page 665 it was mentioned that the focusing was done by combined adjustment of the filament brilliancy and the voltage of the surrounding cylinder. In Fig. 503 it will be seen that the output of the open aerial circuit is applied to the valve V_{10}, in the anode circuit of which are a battery and resistance R_9 the voltage drop down which will render the cylinder more and less negative in alternate half cycles. If the fixed potential on the cylinder be adjusted so that the additional negative thus applied will just provide the correct bias for a sharp image, the positive swing will give a marked defocusing and the image will appear as in Fig. 505. It is normally arranged that the sharply focused half of the line shall indicate the true sense, and the method has the great advantage that bearing and sense are determined at one operation. In case it should be found that a phase reversal is necessary in setting up the apparatus, a phase-change switch is incorporated in the open aerial amplifier as shown, but this switch is not repeated in the frame amplifiers.

For checking up the gain, tuning and phase adjustments of the whole apparatus, a test signal is applied at the three aerial input circuits simultaneously from a test oscillator.

The wave range is 750 to 1,500 m. (400 to 200 kc.). For a more detailed account of the equipment, reference should be made to the publication already mentioned (2803), which also shows photographs of the receiver.

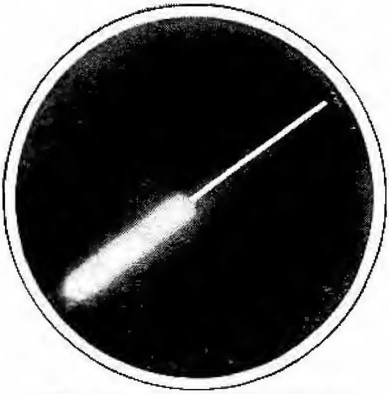


Fig. 505.—Sense Indication by Defocusing of Image.

Advantages of the Cathode Ray Radiogoniometer. Although weak signals are subject to interference on the screen of the tube and are liable to be obliterated by more brilliant images of other signals, there is a difference in the nature of the interference from that experienced in aural reception. As a result of this it is at times far easier to examine the screen bearing of a visual signal than the cosine minimum point of an aural one and a combination of the two has definite advantages.

A further, and perhaps more important, advantage of a visual over an aural type of indicator is the way in which the visual type is able to modify the effects of very short and widely separated signals. Thus, if short pulses of energy of duration equal to say, a fraction of a millisecond, are received using a cathode ray tube, they will cause deflections of the beam, the images of which will persist in the eye for about a tenth of a second. Advantage can be taken of this in the observation of the direction of atmospherics which, although often of very short duration and impossible to D.F. by any aural method, leave a visual impression for long enough a time to note their bearing. A serious disadvantage of the system is that three amplifiers are necessary, thus adding to the cost and necessitating careful lining up when in use.

With the cathode ray radiogoniometer, aural reception is also retained for the purposes of identifying the received station.

THE PULSE DIRECTION FINDER

The Pulse Direction Finder, the principle of which has been briefly described on page 223, was introduced by S. B. Smith and T. L. Eckersley (Marconi Company) in 1932, followed closely by a similar suggestion by E. V. Appleton, L. H. Bainbridge Bell, J. F. Herd and R. A. Watson Watt (Radio Research Board).

In reference (3701), H. Plendl claims to have developed the method independently in Germany and gives an account of work carried out by him and the Deutsche Versuchsanstalt für Luftfahrt from October, 1933, to February, 1934.

The possibility of using the pulse D.F. in aircraft gives it an immediate advantage over the Adcock aerial as a means of eliminating night errors, and the system has a number of further attractive features.

Visual Selection of Signal. The function of the time base unit of a cathode ray equipment has been described on page 667 and in the case of the pulse D.F. the frequency is, of course, adjusted to give a stationary image of the required pulse signal.

Some interesting points arise from this process, one of which is that if the time base be accurately calibrated in cycles per second, it affords a method of station identification. If a series of beacon stations were to be equipped with pulse transmitters, the frequencies of which were fixed at, say, 290, 300, 310, 320 cycles per second, and so on, then on tuning in the beacon with the 300 cycle pulses and setting the time base to this figure, the pulse image should be stationary. If the pulses appeared to be moving rapidly to the right or left on the screen it would indicate that the wrong transmitter had been selected—assuming, of course, that everything else in connection with the transmitter and time base was in proper working order.

Alternatively, if the radio frequency separation of the different pulse transmitters were inadequately performed in the receiver, more than one set of pulses would be visible on the screen, but again the desired ones could be easily identified as they would be stationary whilst the remainder would be moving in one direction or the other at 10, 20 or 30 per second and would cause little interference.

This is, of course, only a visual method of low-frequency tuning or filtering, but permits the isolation of signals when their frequency separation is strikingly small.

The ease of separation of pulse signals from unwanted random signals and noise is a feature of the cathode ray screen. The transmission of pulses, as a means of conveying intelligence, is extremely inefficient owing to the short time during which the carrier wave is being radiated. As a result, telephone signals as produced by pulses in a wide frequency band receiver are comparatively weak. With the tube, however, the position of the frame aerial for the vanishing point of the direct ray pulse can often be accurately distinguished even when the remainder of the screen image is mutilated by noise and jamming signals.

Fig. 506 is a sketch of such conditions at the instant when the direct ray image has been reduced almost to zero. In practice the image may be far more confused than shown here and yet allow of bearings being taken, since the pulses, although blurred and mutilated, are the only stable part of the image, the remainder of which is continually changing in shape and light intensity.

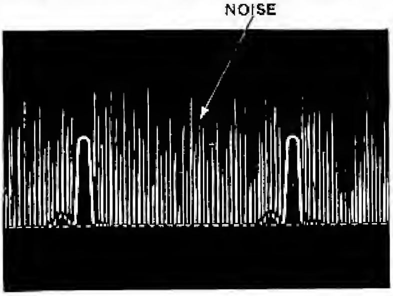
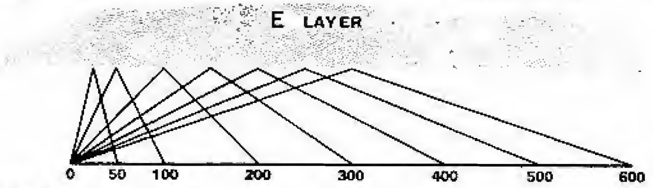


Fig. 506.—Sketch of Pulse D.F. Screen Image Showing Effects of Interference.

Scattering. Yet another important feature is the ability to recognise and to avoid the effect of scattered signal reception which has been seen on page 377 to be capable of interfering with the direct ray reception and also of giving entirely incorrect bearings. Owing to the comparatively wide separation between the direct ray and the scatter images on the oscillograph screen, as seen in Fig. 32, there is never any difficulty in preventing confusion between the two.

Limitations of the Pulse D.F. Since this system postulates a direct ray on which to operate there not only exists a limit to its use on short waves but a new difficulty is encountered which also places a limit on its range on long waves, namely that of distinguishing between the direct and reflected ray images as the range increases. This merging of the two images into one is due to the trajectory of the reflected ray becoming flatter and more nearly equal in length to the direct ray path with increasing range, the effect being exaggerated in the case of long and medium wave lengths since the height of the E layer is in general only about one-third to one-quarter that of the F layer.

Fig. 507 shows the conditions assuming a height of the E layer of 100 km. and it is seen that at a range of 600 km. the time lag between the arrival of the ground ray and the first reflected ray is only little more than one-tenth of a millisecond. In order to distinguish between pulse images at such short intervals it is clear that the duration of the pulses themselves must be a fraction of a millisecond and this at once entails difficulties, not only in the transmission of such short signals, but also due to the production of side-band spread which is liable to lead to serious interference on the long and medium wave band if high powers are used in congested areas.



DIFFERENCE IN LENGTH OF PATH OF REFLECTED AND DIRECT RAY	156	124	83	60	48	38	30
				KILOMETRES			
TIME LAG OF REFLECTED AFTER DIRECT RAY	0.52	0.41	0.28	0.2	0.16	0.13	0.10
				MILLISECONDS			

Fig. 507.—Time Intervals Between Arrival of Direct and Reflected Rays.

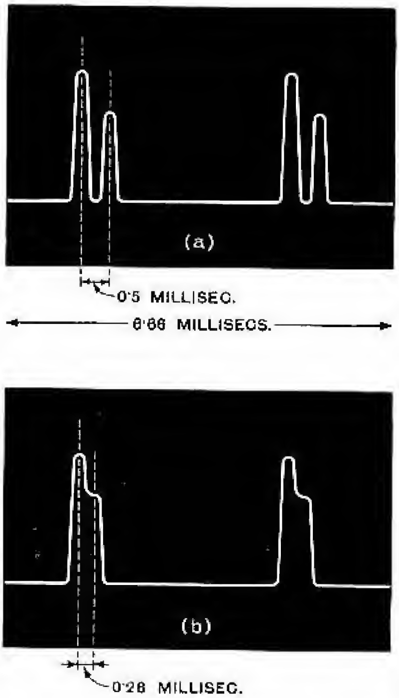


Fig. 508.—Effect of Increasing Range on Screen Image of Pulse D.F.

Fig. 508 shows pulses of 0·3 millisecond duration on a time base of 1/150th second or 6·66 milliseconds with (*a*) a range of 50 km. and (*b*) at a 200 km. range.

A Pulse D.F. with Aural Reception. In a patent* by the Société Française Radioélectrique, a method is mentioned of using a thyratron in a receiving circuit in such a way that

* French patent 793 957.

the first or direct ray pulse may be selected, and the remaining reflected ray signals ignored. It is suggested that bearings might thus be taken on the ground-ray pulse under suitable receiving conditions, and received aurally, without the use of a cathode ray tube.

THE TELEFUNKEN PULSE DIRECTION FINDER, TYPE SPECIAL 2036 N

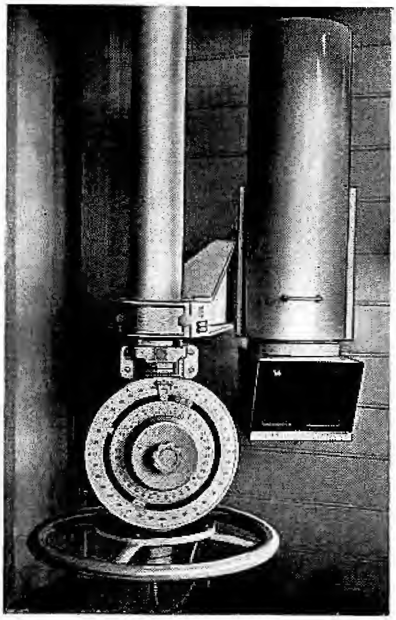


Fig. 509.—Telefunken Pulse D.F. Type Special 2036N.

A pulse direction finder has been produced by the Telefunken Company, and the rotating frame control, scale and cathode ray tube mounting are shown in Fig. 509. This model is intended for use either in fixed or portable shore stations or at sea. It is not adaptable to aircraft work in the form described here. Reference (3701) contains photographs of a later development of the apparatus as installed at Hanover Aerodrome.

The transmitters used in conjunction with the apparatus must be capable of radiating pulses of about one-third millisecond duration at a frequency of 300 per second. As seen from Fig. 507, pulses of 0·33 millisecond permit working up to a range of about 200 km.

The general layout of the circuit is shown in Fig. 510, particulars of the components being as follows.

Frame, Control and Scale. The rotating frame and associated control, cam corrector for local errors, scale, etc., are the same as shown in Figs. 337 and 356.

D.F. Receiver. The receiver is also the same in outward appearance as that used in the ship D.F. described on page 448, but is arranged for bench mounting. The zero cleaning and other controls are the same as previously described.

The wave range is 570 to 1,350 m. (527 to 222 kc.), and there are four ganged stages of R.F. gain, detector with reaction and separate single stages of audio amplification for the pulse

D.F. and for normal D.F. using telephones, these latter stages being in the separate low-frequency amplifier.

Sensitivity. The sensitivity of the apparatus is stated by the Telefunken Company to be as follows.

Using the frame aerial at its maximum position and with telephone reception and oscillating detector, a field strength of about 1 μV/m produces an output of 1 volt across 4,000 Ohms. Without the oscillating detector, the sensitivity is halved. When using the cathode ray tube a field strength of 3 μV/m supplies the requisite voltage of 60 V. to the tube.

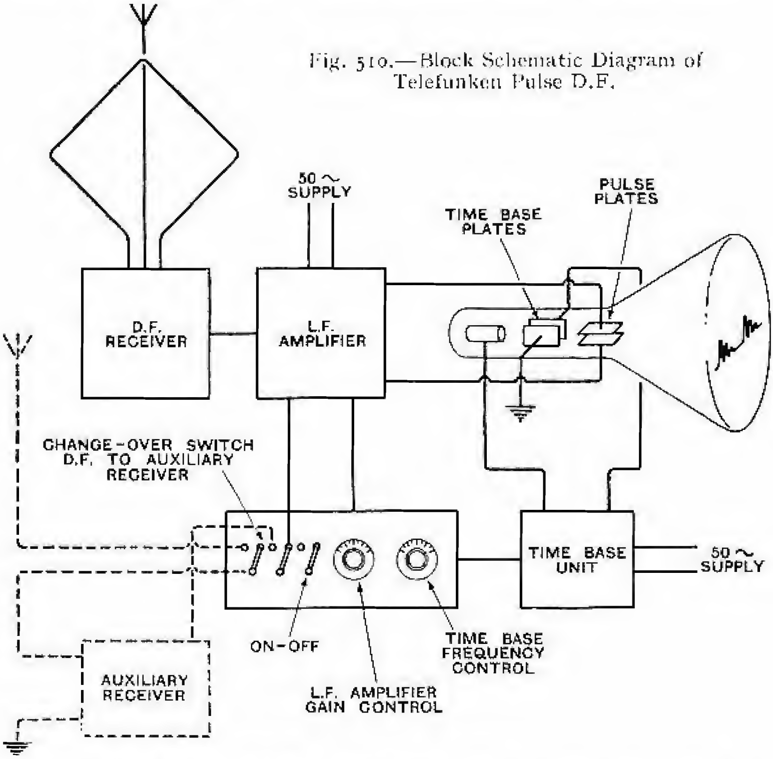


Fig. 510.—Block Schematic Diagram of Telefunken Pulse D.F.

D.F. Field Strength Requirements. For audio D.F., a field strength of 80 μV/m gives a cosine minimum of 1° total width on modulated signals whilst on C.W. signals, 40 μV/m gives the same result. With the tube, a field strength of 100 μV/m is required for 1° width of cosine minimum, but owing to the facility with which wanted and unwanted signals can be discriminated by visual means, as mentioned on page

674, direction finding can actually be carried out with fields as low as 6 μV/m.

Selectivity.

Amount of Detune		Reduction in Output Voltage
Audio D.F.	Pulse D.F.	
0·8%	1·7%	20 db. (to 1-tenth)
1·9%	3·7%	40 db. (to 1-hundredth)
4·5%	10·0%	60 db. (to 1-thousandth)

Low-Frequency Amplifier. The necessary voltage for the tube is derived from a mains unit incorporated in the L.F. amplifier, the gain of which is controlled from a separate unit shown in the centre of the layout.

Time Base Unit. This also uses A.C. mains supply and has a mean frequency of 150 cycles per second so that since the pulse transmission frequency is 300 c.p.s., two images are seen on the screen as in Fig. 508.

Auxiliary Receiver. This is not an essential part of the equipment but allows of a rapid change-over from D.F. to a sensitive non-directional receiver if required.

Operation. The taking of either audio or visual bearings will be clear from the previous description of the receiver in connection with marine work, together with the notes on the principles of the pulse direction finder. The zero sharpening and sense determination are used in identically the same way in both visual and audio methods.

MARCONI "BALANCED PATTERN" CATHODE RAY D.F.

In this D.F., the cathode ray tube is used only on account of certain advantages that it offers as a form of indicator, and the equipment still employs a manually operated rotating loop (or B-T aerials and a radiogoniometer) with scale and pointer. It is therefore not a direct reading instrument in the sense of being automatic.

The fundamental principle of the method is the switched cardioid diagrams of Fig. 398, in which a low-frequency modulation was applied to the radio frequency signal and a dynamometer was used to indicate the phase and amplitude of the low-frequency output of the receiver, as it varied according to the loop orientation. Here the original modulating e.m.f. is applied to one pair of plates of a cathode ray tube and the

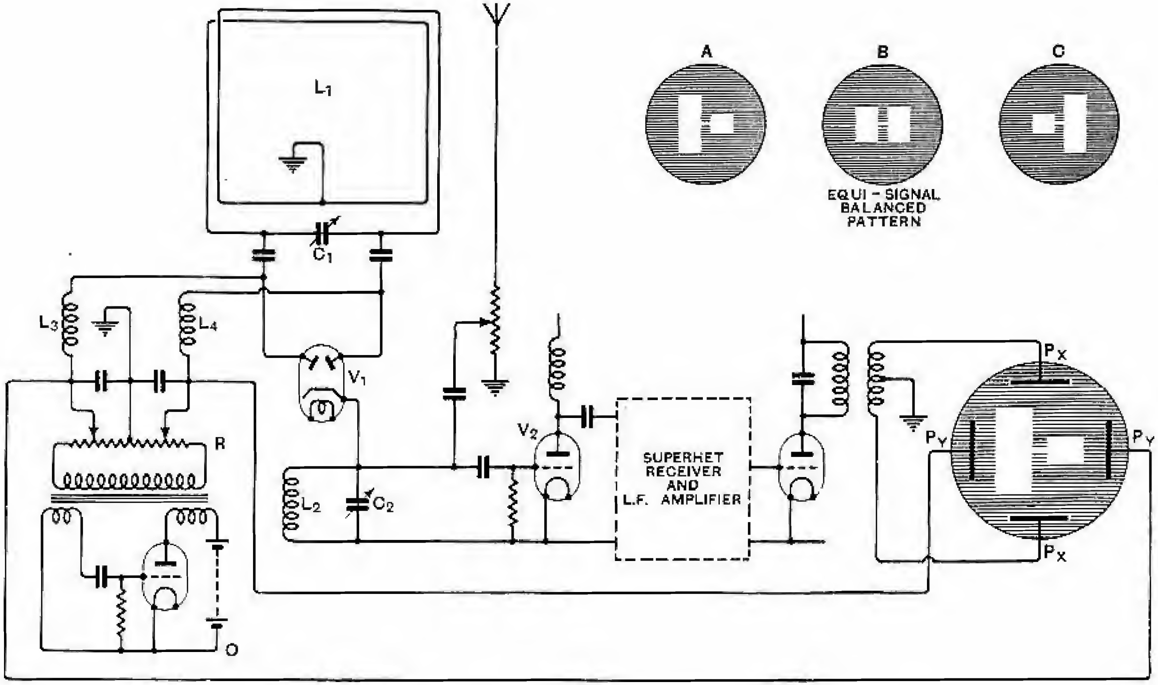

A
B
C
EQUI - SIGNAL BALANCED PATTERN
L_1
C_1
L_3
L_4
V_1
R
O
L_2
C_2
V_2
SUPERHET RECEIVER AND L.F. AMPLIFIER
P_X
P_Y
P_Y
P_X

Fig. 511.—The Marconi " Balanced Pattern " Cathode Ray D.F.

receiver output to the other pair, the shape of the image providing the required information.

Circuit. In Fig. 511 the tuning condenser C_1 of the loop L_1 is connected through blocking condensers to the anodes of the double diode V_1, the cathode of which is connected to the high-potential side of the oscillatory circuit L_2 C_2 in common with a resistance-phased open aerial. A low-frequency valve oscillator circuit O has, across its output transformer, a potentiometer R, with earthed mid-point and with sliders connected through chokes L_3 L_4 to the anodes of V_1 and also to the Py plates of the cathode ray tube. The result of the application of the A.C. voltage to the Py plates is a horizontal trace on the screen of the tube.

The A.C. voltage is also applied, in the same phase, to the double diode, and due to the centre tap of the potentiometer, the e.m.f.'s on the two anodes are in opposite phase, so that the diodes are biassed one positively and one negatively, with changing sign each half cycle. This causes the resistance of one diode to drop to a negligible value, whilst that of the other is several megohms, and vice versa.

The loop circuit is connected to L_2 C_2 through whichever diode is positive, and in this manner the loop signal is applied to the valve V_2 and the receiver and amplifier, with phase reversals at the frequency of the low-frequency oscillator circuit. The open aerial is assumed to be disconnected for the time being.

If, now, after rectification and low-frequency amplification, the output is applied to the Px plates of the tube, the amplitude of the loop signal, if any, is represented on the screen as a balanced image, as shown at B, in which the two halves are produced alternately by whichever diode is positively biassed. As the loop is rotated through the position of signal minimum, the vertical amplitude of the complete image will fall to zero and rise again, retaining the balanced pattern, so that this does not provide a means of taking a bearing by an equi-signal comparison method.

It will be apparent, however, that since the phase of the loop signal changes at each half-cycle of the low frequency, switched cardioids will be produced if the open aerial be connected as shown in the diagram, in the manner already described in connection with Fig. 398. Under these conditions, when the loop is in the position of zero signal, each half of the balanced pattern is due to the open aerial signal with no signal from the double diode, as shown at B. Any movement of the loop, clockwise or anti-clockwise, will, however, produce patterns similar to those shown at either A or C, the discrepancy in the amplitudes of the two halves increasing to a maximum at a 90° loop rotation.

Sense is determined in the way described on page 509 in the case of aircraft homing apparatus, namely, by noting which half of the diagram increases in amplitude for, say, a clockwise swing of the loop.

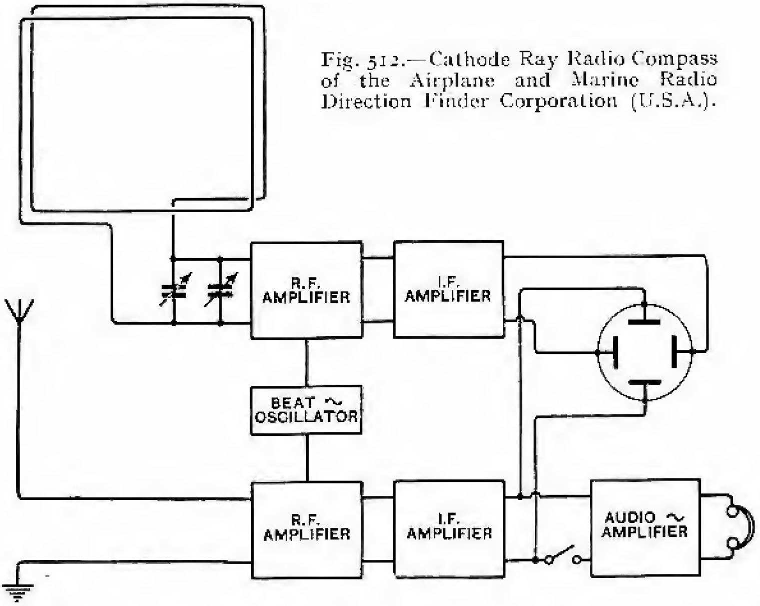


Fig. 512.—Cathode Ray Radio Compass of the Airplane and Marine Radio Direction Finder Corporation (U.S.A.).

Advantages of the Method. The cathode ray method of indicating equi-signal balance has the advantage of being far more free of interference from atmospherics and appreciably more easy to read through jamming, than is an aural method, whilst its complete lack of mechanical inertia eliminates the random swinging of the needle of a magnetic form of indicator under these conditions.

CATHODE RAY RADIO COMPASS OF THE AIRPLANE AND MARINE RADIO DIRECTION FINDER CORPORATION (U.S.A.)

A radio compass has been produced by the above Corporation (3620) in which a cathode ray tube is used as an indicating device, the on-course and off-course positions, also proximity to and passage over the transmitter being represented by characteristic images.

A block schematic circuit diagram is given in Fig. 512 from which it is seen that a loop and an open aerial are used, the former being fitted at right angles to the centre line of the aircraft. Each aerial has its own superheterodyne receiver with a common beat oscillator, the receiver outputs being taken to the pairs of plates of the cathode ray tube, the open aerial controlling the vertical image.

With the open aerial signal alone, the diagram of Fig. 513(*a*) is obtained and similarly when the loop and open aerial are operating together this image results so long as there is no loop signal, that is to say so long as the aircraft is heading directly to the transmitter.

When a loop e.m.f. exists and is applied to the horizontal plates in phase with the open aerial e.m.f., the image will be as in (*b*) or (*c*), where the tangent of the angle of slope from the perpendicular is a measure of the ratio of loop signal to open aerial signal. If the two e.m.f.'s are in quadrature, the result will be as in (*d*); if at some intermediate phase relation the image will be an ellipse with its major axis sloping away from the vertical.

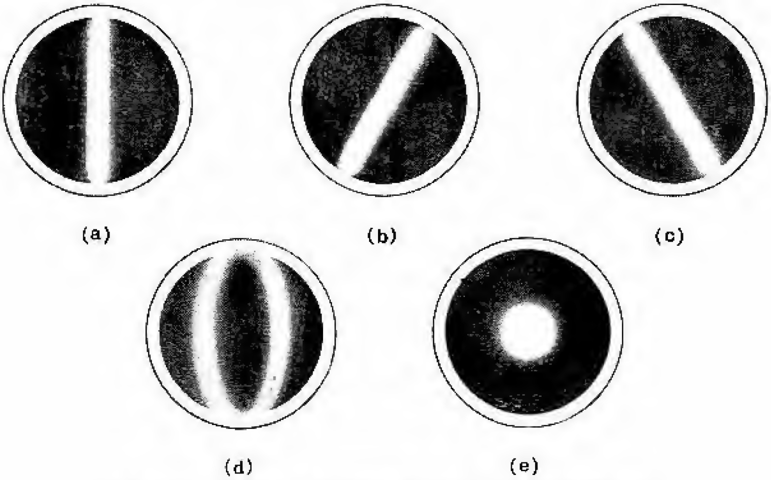


Fig. 513.—Screen Indications given by D.F. of Fig. 512.

The series of images will, in fact, provide an exact analogy to the set of diagrams of Fig. 11 in relation to the rotating electromagnetic field.

The elliptical image is converted to a sloping line by the small phasing condenser in parallel with the loop tuning condenser, and once correctly lined up on a given signal, does not require any further adjustment.

Homing. The apparatus is normally connected so that when the aircraft is flying towards the transmitter and turns right, the image rotates to the right, or clockwise. The relative direction of the movement is reversed when flying away from the transmitter and this gives sense indication in the way already mentioned on page 509.

When passing vertically over the transmitter, or at least

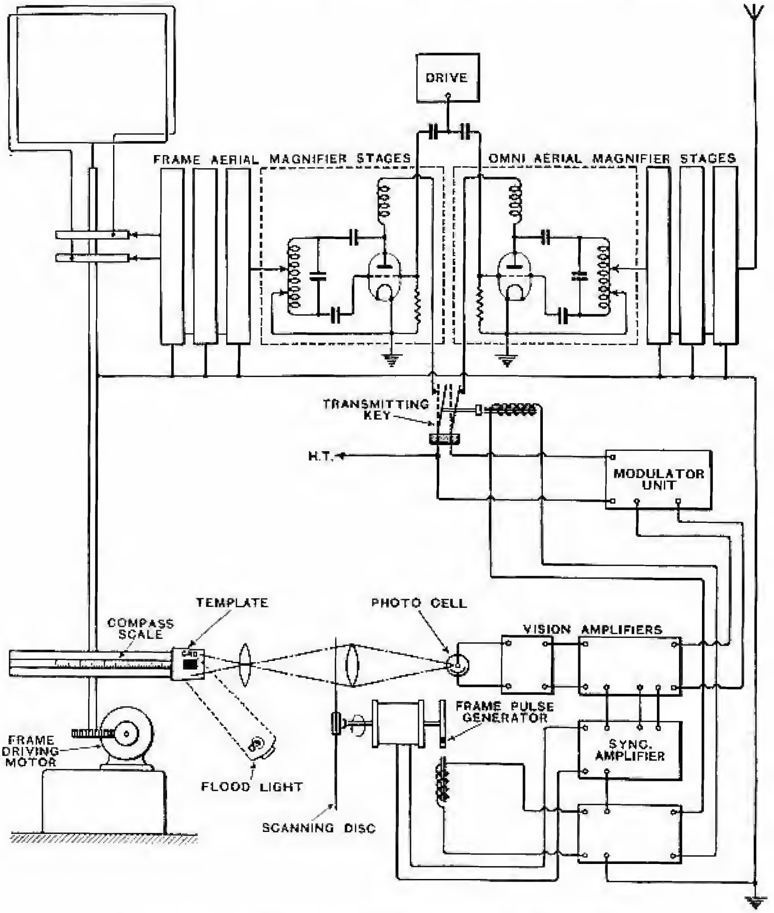


Fig. 514.—Marconi Television Beacon Transmitter.

passing through the zone of minimum radiation, one or other and possibly both aerial e.m.f.'s will be reduced to a small value and the image will become a circle as in (*e*). As the shape of the polar diagram of radiation and also the polarization of the electromagnetic field in the area above the transmitter vary largely with the type of aerial, and as both these factors, together with the shape of the receiving antenna in the aircraft, control the received e.m.f., the screen image will in some cases pass through a sequence of shapes. These, when once familiar, will indicate the passage over the transmitter with considerably more certainty than is possible with aural reception.

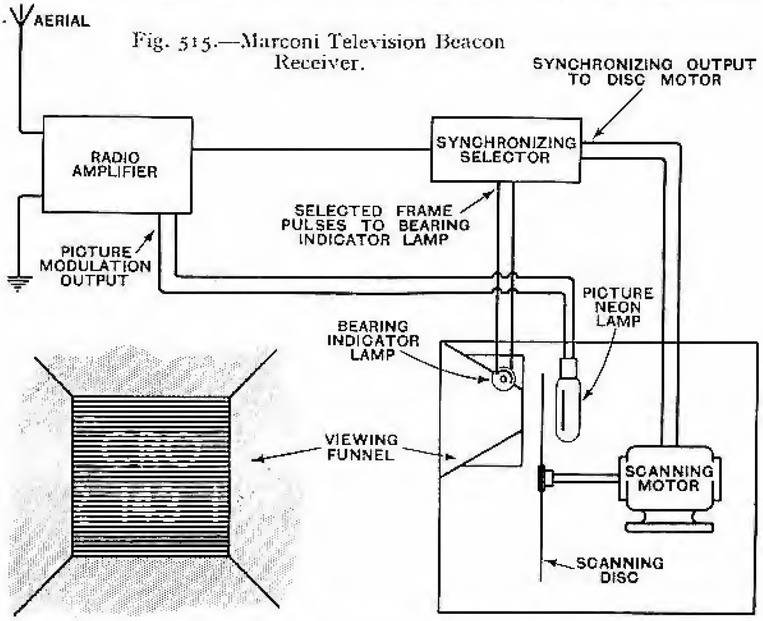


Fig. 515.—Marconi Television Beacon Receiver.

DIRECT READING D.F. APPARATUS EMPLOYING TELEVISION

The Television Beacon. In the rotating beacon using a simple loop, it was seen that the signal intensity at the receiving point followed a cosine law and was reduced to zero twice in each rotation of the beacon. In a 1928 patent,* due to J. Robinson, it is suggested that the beacon shall radiate a television picture of a portion of a circular scale that rotates with the beacon loop. The scale is calibrated from 0° to 359° and the portion radiated includes a fixed pointer so that the received image illustrates continuously the changing orientation of the loop.

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* British patent 327 112.

Owing to the fact that the beacon has a cosine diagram of radiation, portions of the image will be lost twice in each rotation, which will correspond to the direction of the cosine minimum. Hence the missing portions of the scale represent the true bearing of the receiving point from the beacon.

The fundamental obstacle to any television system using other than ultra-short wave lengths, is the band width required to produce a suitable image, and in the beacon band of frequencies there is particularly little room to spare. Fortunately the intelligence to be conveyed in this case is very simple and need consist only of the identification letters of the beacon and a number representing the bearing. It is found that a band width of only 3 kc. suffices reasonably well, as shown in Fig. 515.

In the apparatus described below, the disadvantage of the varying signal strength and the loss of the signal altogether at the critical moments has been overcome, though the basic principles have much in common with the Robinson method.

THE MARCONI TELEVISION BEACON

A simplified diagram of the transmitter of a form of television beacon is given in Fig. 514 and includes an open aerial and a continuously rotating loop. Mounted on the shaft of the loop is a compass scale, which passes across the opening in a fixed window or template, the latter being marked with the identification letters of the beacon, and illuminated.

An image of the template and scale sector is projected through a spiral scanning disc and the light passed by the disc apertures is focused on to a photo-electric cell. The variations in light intensity, due to the scanning of the scale and template, then develop corresponding voltages which are amplified and used to modulate the open aerial transmitter. This aerial, therefore, radiates a television picture of a sector of a rotating scale whose calibration relates to the position of the frame with regard to true North, at any instant.

The synchronizing signal is obtained from a special winding on the motor driving the scanning disc, and is radiated with the television signal. In this way, a constant level of picture and synchronizing signal is obtained.

The bearing intelligence is transmitted by the frame aerial, and in order that the two transmissions may not combine and so prevent a true cosine diagram from being received, the frame aerial is made inactive whilst the open aerial is transmitting, and vice versa. This is done at the same frequency as that at which each picture " frame " is completed.

A picture frame constitutes one revolution of the scanning disc and each picture is interrupted during a portion of each rotation. During this interruption, which occupies approximately one quarter of the framer period, the loop aerial is made active. The resultant aerial radiation is then distributed in the following way.

During the framer period, which occupies, say, $\frac{1}{10}$ of a second, picture is transmitted for $\frac{3}{40}$ of a second and a C.W. pulse is radiated from the loop for $\frac{1}{40}$ of a second. This is accomplished in practice by a pulse generator driven by the scanning motor, the generator comprising a disc fitted with an iron segment, which, once per revolution, passes over a cored inductance coil and generates an e.m.f. By subsequent amplification and reshaping, this pulse can be made to operate a transmitting key, the contacts of which apply D.C. H.T. to the open aerial amplifier when energized, and modulated H.T. to the loop amplifier when released.

Receiving Equipment. The received intelligence then includes :

(1) A television picture of a scale, pointer and identification letters.

(2) A steady synchronizing pulse.

(3) A succession of C.W. pulses, occurring at $\frac{1}{10}$ second intervals, and which vary in amplitude from zero to some maximum, according to a cosine law, as the transmitting loop is rotated.

The television image may be viewed on a cathode ray tube or by scanning disc, as in Fig. 515, the reception of the picture conforming to normal television practice. The bearing indication, however, calls for additional circuit arrangements and it is usually done by means of a neon tube that is extinguished at the instant at which the bearing must be noted.

This lamp is operated by the pulses radiated from the loop and, in order that they may be selected from the vision intelligence, the modulation depths of the vision and bearing pulse are made different. In general it is convenient to arrange that maximum white on the picture represents maximum carrier amplitude, and that maximum black represents 30% modulation. The bearing pulse is also transmitted slightly later than the cut-off of the vision carrier, so that at either side of the pulse, zero carrier exists. The " wave form " of each line thus appears as in Fig. 516 where the picture modulation varies from 100% to 30% and the directional C.W. pulses, from the loop transmitter, from 100% to zero. The received voltage due to this signal is now applied to a circuit in such a way that any modulation below 30% reduces the negative bias on the grid of a valve, as suggested by the $E_g - I_a$ characteristic CXC, and operates the neon lamp, which is arranged to be extinguished for zero signal, corresponding to cosine minimum.

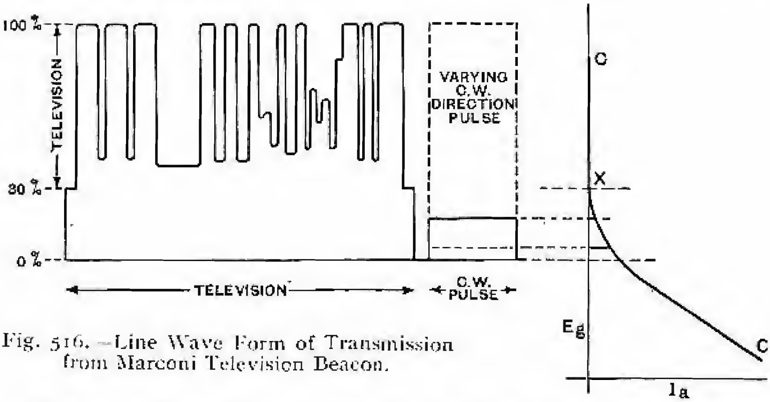

Fig. 516.—Line Wave Form of Transmission from Marconi Television Beacon.

The neon lamp illuminates the inside of a view tunnel at the end of which the picture appears. This method is adopted because the operator's eye is already focused on the image and it is necessary to give an indication of the required scale reading which does not require any additional occupation for the eye.

Sixteen lines are used in the image, which appears somewhat as in Fig. 515, and includes a little less than 2° of the scale.

DIRECT READING SYSTEMS USING PHASE-METER INDICATION

In this type of direct reading D.F. it is arranged that the phases of two alternating currents shall be given an angular relation that is equal to, or proportional to, the angular difference between the plane of the wave front of the received wave and some standard. The sources of the two alternating currents are synchronized; the two components may be actually supplied from the same original source or, in certain applications of the system, one component may have its frequency doubled.

Having obtained the above-mentioned phase relation, it only remains to measure it in some form of phase-meter, which can be calibrated to read the desired bearing in degrees from true North or from the head of the ship or aircraft.

There are two ways in which the phase of one of the alternating current components is given the required shift, and both involve the modulating of the radio frequency signal from a loop aerial or from B-T loops. These methods are described in connection with the systems mentioned below.

BUSIGNIES DIRECT READING HERTZIAN COMPASS

In the case of the apparatus bearing the above title, it will be found that the modulation is applied to the signal by

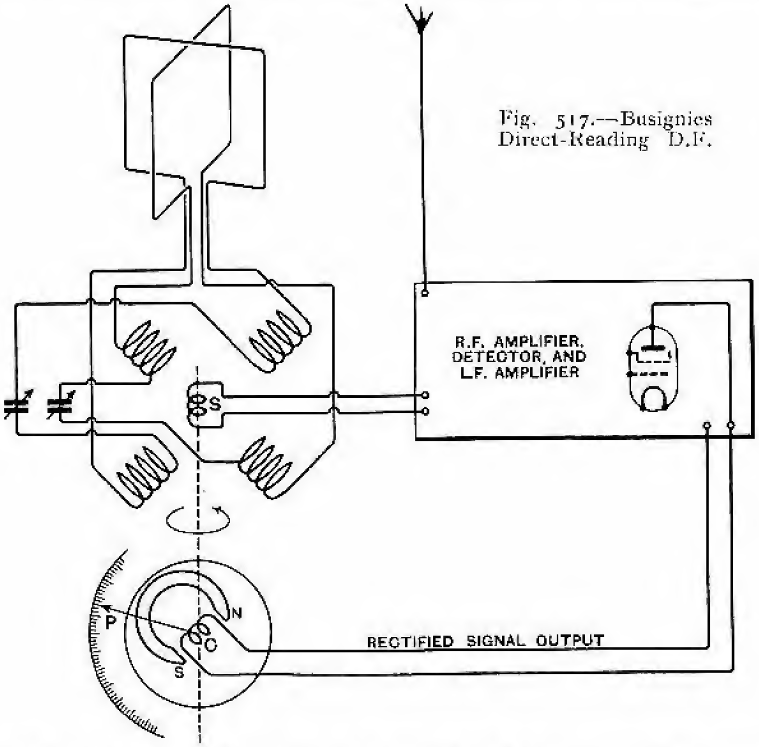

Fig. 517.—Busignies Direct-Reading D.F.

continuously rotating the loop aerial and so impressing, upon the radio-frequency signal, a low frequency equal to the speed of rotation of the loop. The rotating field for the phase meter is provided by the mechanical rotation of a magnet system synchronously with the loop.

The principle of the instrument may be explained by reference to Fig. 517. S is the search coil of a Bellini-Tosi system, or a loop aerial, which is mounted on a vertical shaft free to rotate and which also carries the magnet of a galvanometer, the coil of which, C, is connected to the output of the receiver.

An open aerial provides a cardioid diagram of reception, and as the search coil and magnet system rotate at a uniform speed of 600 r.p.m. the amplitude of the received signal follows a cardioid law, rising to a maximum and falling to zero once in each revolution. The aerials are connected to the receiver as shown, the signal being amplified and rectified following which there is low-frequency amplification, the output being the low-frequency modulation component due to the loop. The phase of this low frequency will clearly be controlled by the radio-frequency signal, for the maximum and minimum signal outputs will coincide with the maximum and minimum receiving positions of the loop. The output is then applied to the coil C which is free to rotate under the combined influence of the current it carries and the flux of the magnet system, providing a form of phase-meter.

The Phase-meter. If a coil be situated in a magnetic field as in Fig. 518, the coil, if carrying a current and free to rotate, will always tend to move so as to link with the maximum magnetic field, the torque being a function of the current and the flux and proportional to sin θ. In other words, the torque varies with the number of magnetic lines remaining unlinked and approaches zero as the angle θ is reduced to 0°.

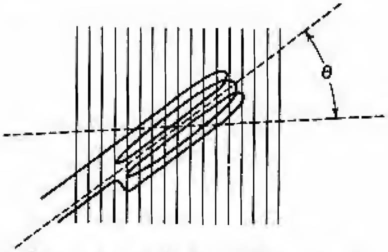

Fig. 518.—Coil C, of Fig. 517, in Rotating Magnetic Field.

At the instant of cardioid maximum, therefore, when the current in C is a maximum, the coil rotates to a position of maximum linkage, and, since the magnet system is rotating with the search coil, this will occur each rotation at the same point and the pointer P can therefore be arranged to indicate the direction of the received signal.

The exact theory of the system thus demands the integration, during a succession of cycles of loop rotation, of the couples that tend to maintain the small coil in equilibrium and if this process be carried out completely, the coil, due to air damping and inertia, etc., will be perfectly motionless when under the influence of the signal.

This is found to be a disadvantage as errors occur due to the initial friction. The speed of rotation of the loop and the mass of the moving coil system have therefore been designed so as to leave a 0·25° vibration to either side of the balance position.

As in the case of some other forms of direction finder from which the human element has been largely eliminated, it is subject to error due to interference from signals on the same frequency as the desired signal, and becomes unworkable if the jamming signal is sufficiently strong.

Precision. It was seen that in the position of maximum flux linkage, the coil in Fig. 518 and zero couple. It is only when the coil moves from the position of maximum linkage that the restoring force proportional to sin θ comes into action, and, for values of 1° or 2°, sin θ is extremely small, so that the system will be susceptible to any spurious currents flowing in C which will thus produce errors.

But the fact that C is in the rotating field of its magnet will cause an e.m.f. to be induced and also a current if there be a closed circuit. This current is reduced to a minimum by choosing the final rectifier valve of such high internal resistance that this e.m.f. of about two or three volts results in a current in C of only some 0·06 milliamperes, whereas the signal output is never less than 6 milliamperes at the cardioid maximum. Under such conditions, the coil will be in equilibrium with an error of 0·6°.

For details of the system and particulars of the methods by which some other defects are overcome, also regarding the employment of the cosine instead of the cardioid diagram, reference should be made to (2702), (2715), (3018), (3128).

INTERNATIONAL MARINE RADIO COMPANY LIMITED (LONDON) TYPE R.C. 1 DIRECTION FINDER

An example of the commercial application of the principle of the Busignies Hertzian Compass, just described, is given in Fig. 519 which shows the Type R.C.1 D.F. of the above Company, installed in a naval vessel.

The motor drive for the rotating loop is fitted in the upper part of the metal case of the apparatus and is easily accessible from the back. The D.F. also has a hand control for the loop, enabling it to be used as a non-automatic type if required.

Provision is made for the control of the scale of the D.F. from the Sperry Gyro Compass so that true, instead of relative, bearings may be indicated.

The remainder of the constructional details may conveniently

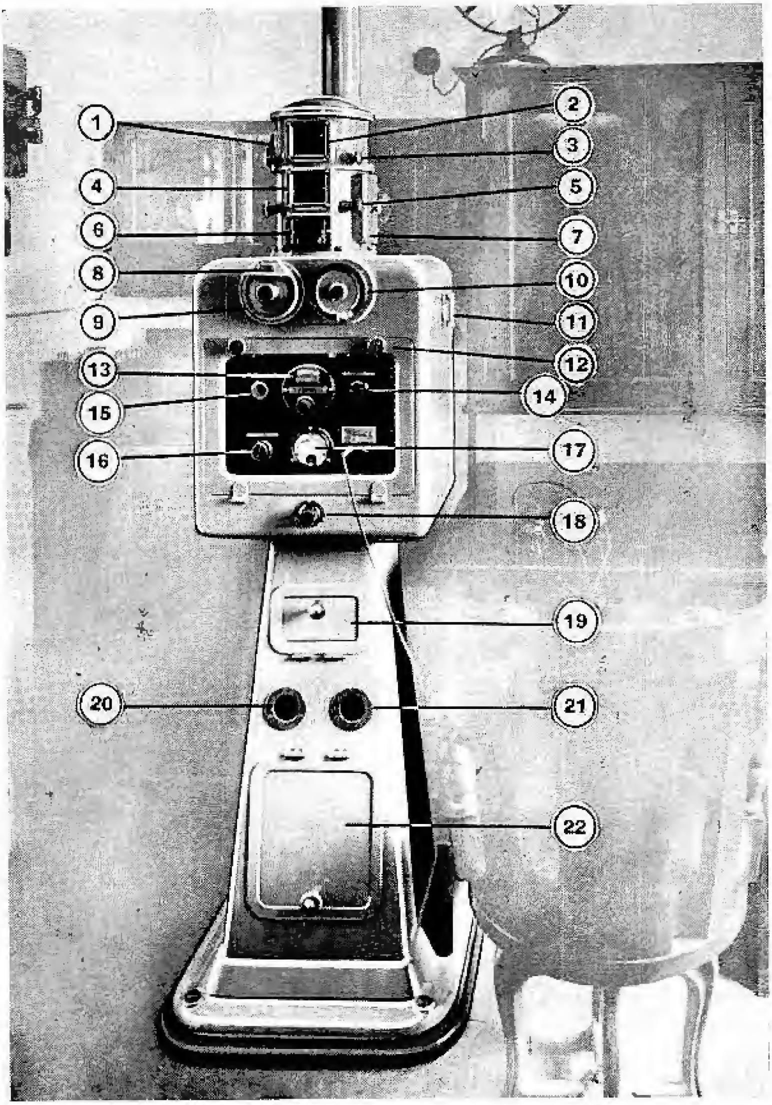

Fig. 519.—International Marine Radio Company Type R.C.1 D.F. (Automatic Direct Reading).

be examined by comparison of the illustration with the following explanatory list:

(1) Inspection plate for locking Sperry Repeater.

(2) Illuminated prism for reading dial of Sperry Repeater.

(3) Adjusting and locking knob for above prism.

(4) Illuminated prism for reading dial of automatic indicator.

(5) Adjusting and locking knob for above prism.

(6) Illuminated magnifying glass for dial used for manual bearings.

(7) Inspection door.

(8) Magnifying glass for reading (9).

(9) Circular scale device for converting relative to magnetic bearings, knowing the ship's course.

(10) Hand-wheel drive for non-automatic operation.

(11) Oil gauge and drain cock, for loop drive.

(12) Front frame of amplifier panel, hinged on bottom edge, and falling to horizontal position to support amplifier when withdrawn for inspection.

(13) Ganged tuning control.

(14) Reaction control for C.W. reception.

(15) Balancer for quadrature effect.

(16) Volume control.

(17) Received signal output current in milliamperes.

(18) Main switch.

(19) Cabinet for telephones.

(20) Green lamp signal from W/T office.

(21) Red lamp signal from W/T office.

(22) Pedestal compartment containing motor-generator set.

Rotating Loop. The loop is contained in a bakelite housing shown in Fig. 520. The open aerial is mounted above the loop whilst on the sides of the housing may be seen adjustable metal plates which are used for the correction of quadrantal error.

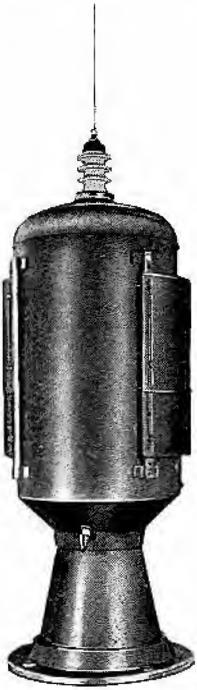

Fig. 520.—Housing for Rotating Loop of I.M.R. Co. D.F. shown in Fig. 519.

STANDARD TELEPHONES AND CABLES LTD. TYPE R 5 DIRECT READING AIRCRAFT DIRECTION FINDER

The basic principle of this apparatus is again that of the Busignies "Hertzian Compass" (see page 680) but the method of application has been considerably changed, and is described by H. Busignies in (3607) and (3705), the new automatic compass being the product of Le Matériel Téléphonique, Paris, associated with Messrs. Standard Telephones & Cables Ltd.

In the present case a loop is used and again rotates at 600 r.p.m. but instead of the field magnet system of the indicating meter rotating in synchronism, a rotating field is produced in a stator winding, the rotor of which carries the indicating pointer as shown in Fig. 521.

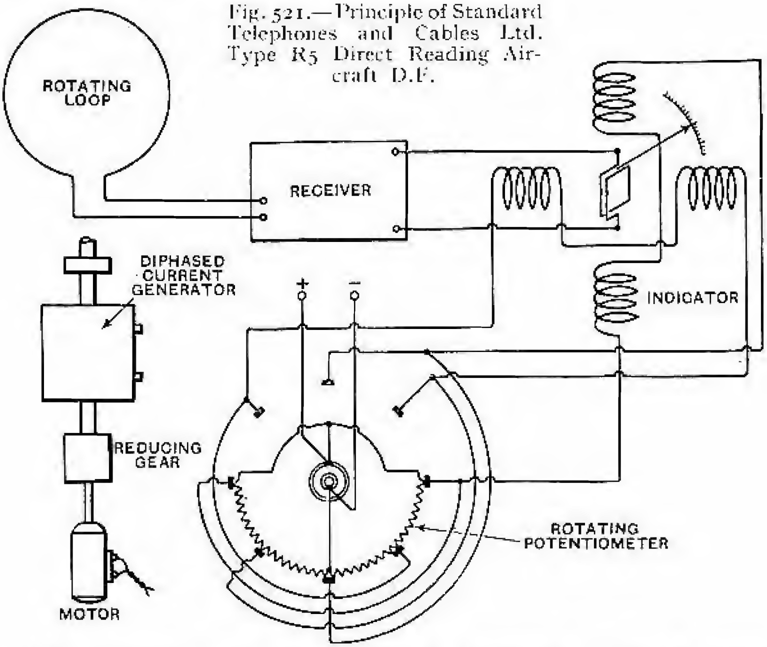

Fig. 521.—Principle of Standard Telephones and Cables Ltd. Type R5 Direct Reading Aircraft D.F.

The radio frequency signal, which, due to the cosine diagram of reception, will have two maxima and two minima per revolution, passes to an amplifier and rectifier, the output having a frequency equal to twice the speed of rotation of the loop as shown in Fig. 522. It is therefore necessary to make the stator field rotate also at twice the loop speed, and this is done by means of a special form of rotating semicircular potentiometer that is fed with a D.C. supply and has a system of collector brushes as illustrated in Figs. 521 and 523. This is termed a diphased generator and it is mounted on the loop spindle, the whole being driven through reduction gearing by a small motor as seen in Fig. 524.

The potential distribution along the potentiometer winding, together with the brush gear connection and distribution to the stator windings will be seen to produce the two wave forms in quadrature as in Fig. 523. The single "stepped" sine curve below shows the actual wave formation from the generator, the steps being due to the finite number of commutator segments connected to the potentiometer winding, but the variations are smoothed out by the inductance of the stator.

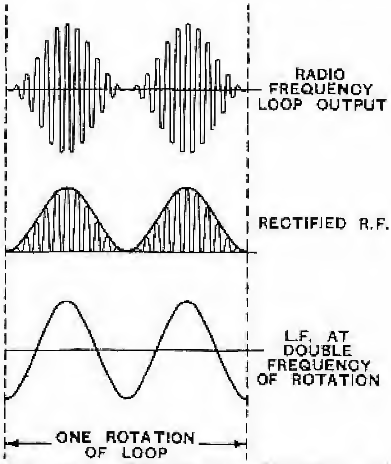
RADIO FREQUENCY LOOP OUTPUT
RECTIFIED R.F.
L.F. AT DOUBLE FREQUENCY OF ROTATION
ONE ROTATION OF LOOP

Fig. 522.—Frequency Doubling of Output of Loop in Fig. 521.

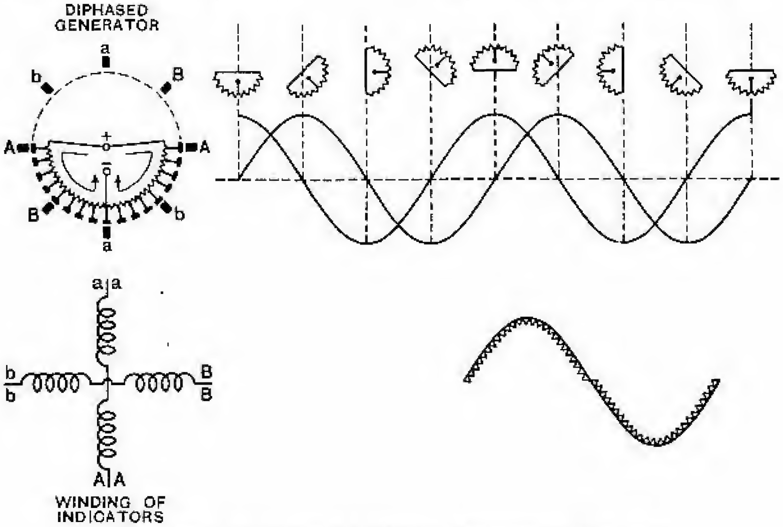

Fig. 523.—Principle of Diphased Generator of Fig. 521.

In the indicator, the magnetic reaction of the signal flux on the stator flux results in the rotor taking up a steady position representing the direction and sense of the incoming signal relative to some origin. This origin is a function of the phase of the diphased generator output with regard to the plane of the loop, and by a simple mechanical means it is possible to adjust this so that the indicator pointer is at 0° for a signal arriving from a direction straight ahead of the aircraft. As in the case of the earlier model, the inertia of the rotor is limited so as to allow a vibration over about $\frac{1}{4}^\circ$, which lowers the initial friction and gives a visual indication that the apparatus is "alive."

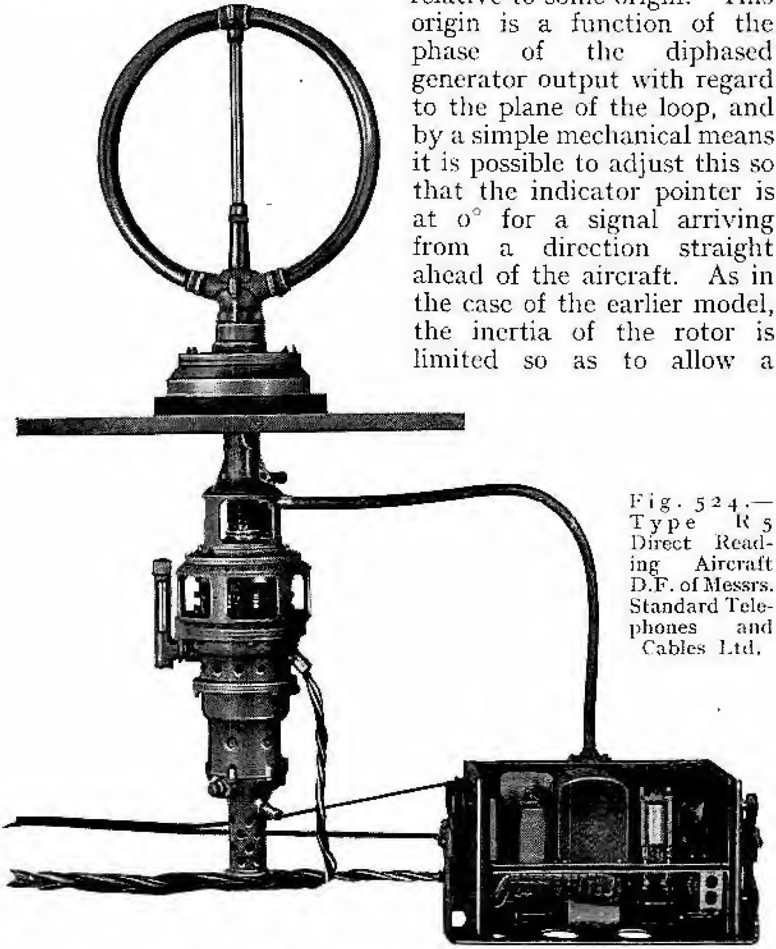

Fig. 524.—Type R 5 Direct Reading Aircraft D.F. of Messrs. Standard Telephones and Cables Ltd.

Indicators. Fig. 525 shows one of the indicators, of which there are two types. The "navigator's indicator" has a circular moving scale and enables bearings to be observed over the full 360°, but the "pilot's indicator," which is illustrated, has a limited movement and is intended to be used by a pilot who is flying a homing course and to whom a pointer with a line opposite which this pointer is to be held, is a less confusing combination than a fully calibrated scale. The scale is movable through ±15°, and the pointer, which is fixed in the case of the navigator's indicator, may be moved through ±15° to make allowance for drift and for "off-course homing." The sectors on either side of the central mark on the scale are coloured red and green respectively.

Loop. The loop has a diameter of 0·3 m. and its aerodynamic drag is about 6 lb. at 100 m.p.h., which is increased during the rotation of the loop by an amount varying between 3½ and 7 ounces.

Other Data. The total weight, including two indicators, is 70 to 77 lb. depending upon the lengths of connecting cables and controls.

Frequency range: 183–400 kc. (1,640–750 m.).

The distance range over land, by day, is said to be 200 miles on signals from a transmitter with 0·5 kW. in the aerial and 1,000 miles from a 100 kW. transmitter. The range over sea is double that over land.

The accuracy claimed is ± 2° at 310 miles from a transmitter having an aerial power of 300 watts.

The power consumption is not more than 100 watts when

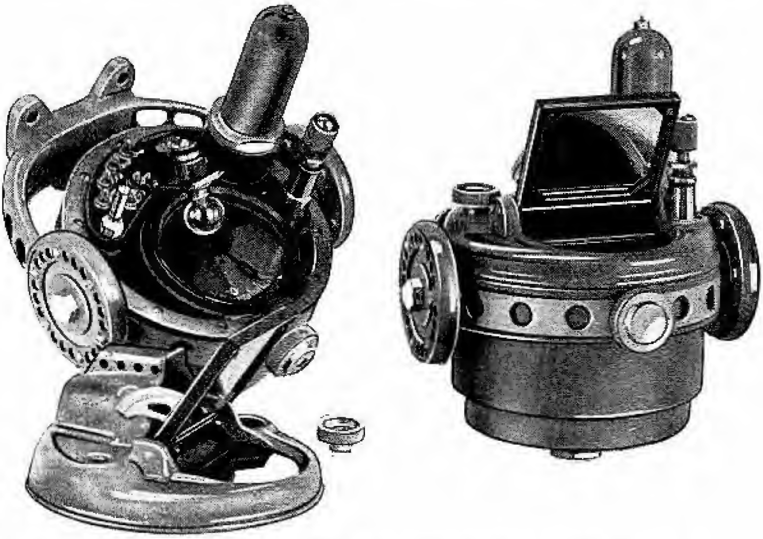

Fig. 525.—"Pilot's Indicator" used with the D.F. shown in Fig. 524.

on D.F. and 50 watts when using the receiver alone. The H.T. is from a rotary transformer operating from the main battery of the aircraft.

OTHER PHASE-METER SYSTEMS

Methods having much in common with that described above have also been put forward by Whitten-Brown,[*] by Berndorfer and Dieckmann (3008), and by Levy.[†]

In an American suggestion due to Electrical Research Products Inc.[‡] the receiving loop is rotated as before, but the comparison in the phase-meter is made between the phase of the output modulation from the amplifier and a current derived from the rotation of the loop in the earth's magnetic field.

The bearing indicated is thus a magnetic one, and from what has been said in Chapter 13 regarding drift of aircraft, the possibilities of such a scheme for maintaining straight flight when homing are at once apparent.

DIRECT READING SYSTEMS USING OPTICAL INDICATION

Braillard and Goldschmidt System. A form of direct reading D.F. is shown in Fig. 526 in which a continuously rotating loop is carried on the same spindle as a drum, on which a stylus marks a horizontal line unless deflected by an electromagnet. The signal from the loop is amplified and rectified, and the D.C. output used for the above purpose. If now a paper scale on the drum be marked with degrees and the whole system correctly registered with respect to the plane of the loop, the position of the stylus on the scale and the direction of North, then a cosine diagram, in extended or Cartesian co-ordinates, should be marked out and will indicate the bearing.

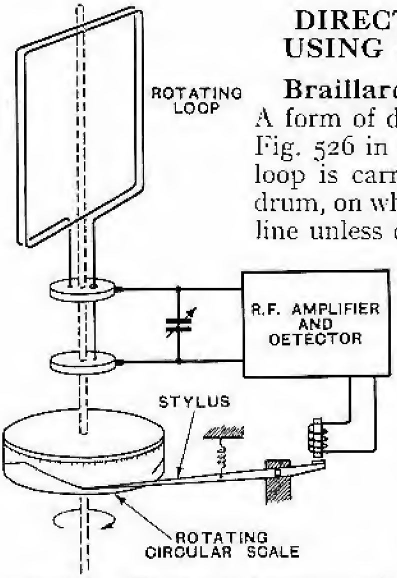

Fig. 526.—Braillard and Goldschmidt Direct Reading D.F.

The use of a rotating mirror is suggested by the above inventors as an alternative to the mechanical indicator, the mirror being mounted on the rotating spindle and at the centre of the drum scale, which is now made of translucent material. The output from the amplifier and rectifier causes the mirror to deflect a beam of light thrown on the inside of the drum, and viewed from outside the drum the persistence of vision causes the rotating spot of light to trace out a line of the same form as that drawn by the stylus above.

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[*] British patent 339 664. [†] German patent 488 999. [‡] British patent 408 211.

Marique System. The Braillard and Goldschmidt optical D.F. has been somewhat improved upon by J. Marique, who arranged the screen in the form of a horizontal ground glass plate, on which the complete polar diagram of reception was thrown as in Fig. 527. A vertical aerial was also incorporated for sense determination.

The mirror system is arranged so that in the absence of a signal the spot of light traces a circle of about four inches diameter, which registers with a circular scale on the glass sheet. On receipt of a signal, the circle is distorted in positions corresponding to either the cosine maxima or minima, depending upon the arrangement of the circuit used, and the bearing can be read off (3116).

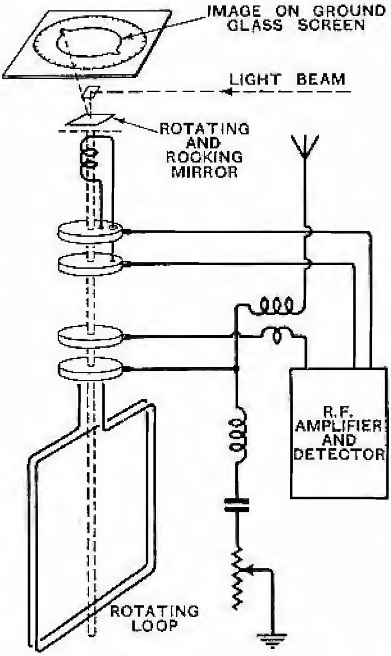
IMAGE ON GROUND GLASS SCREEN
LIGHT BEAM
ROTATING AND ROCKING MIRROR
R.F. AMPLIFIER AND DETECTOR
ROTATING LOOP

Fig. 527.—Marique Direct Reading D.F.

This method of indication does not seem to have given good precision, and in a modified system, due to Marique, a rotating neon tube is used. The signal from the loop, after amplification and rectification, is arranged by means of a simple valve circuit to keep the neon tube glowing only when there is no signal. If, now, a steady transmission such as a telephony carrier, be tuned in on the receiver and the loop set in rotation, the neon tube, rotating synchronously with the loop above a horizontal scale, will glow only as the loop passes through the position of cosine minima, and will be extinguished during the rest of each revolution. Persistence of vision will result in a narrow sector of the scale being illuminated, the centre of which will be the required bearing. A cardioid circuit can be used if desired.

In the form just described the system has the disadvantage that any interfering signal will result in the neon tube being prevented from glowing in the cosine minima positions of the wanted signal. During intervals in the jamming, however, intermittent flashes of the neon tube will be seen in the correct positions and the system is probably no more subject to interference than is an aural method in similar conditions.

An application that has had experimental trials is the wireless guidance of ships into a harbour during fog. Using a 100 m. wave length with transmitters situated one at each side of the harbour entrance, the bearings of both transmitters were given simultaneously, signals being strong enough to preclude any chance of jamming. The position of the ship relative to the two beacons was therefore continuously indicated.

A steady carrier signal was mentioned above as being the easiest transmission on which to make observations, but morse signalling and beacon transmissions are quite satisfactory, except that the indication is intermittent.

Other optical direct reading D.F. systems are described in references (3101), (3209), (3302), (3315), the last three referring to the same equipment; also in two Telefunken Company patents.*

THE " HUNTING " TYPE OF DIRECT READING D.F.

In this type of direct reading D.F. the circuit and the mechanism of the system are designed automatically to search for either the maximum or the minimum signal position by rotation of the loop, the latter then coming to rest and indicating the bearing by means of a pointer and scale. The name " hunting " is applied because in the process of searching, the loop will oscillate back and forth about the final position before coming to rest.

H.M. Signal School Automatic D.F. An example of the above type, due to J. F. Coales, is described in reference (3406), in which the behaviour of a transformer under the influence of increasing or decreasing primary current is used to enable the selection to be made between increasing and decreasing signal e.m.f.

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* British patents 317 826.
345 899.

In Fig. 528 the search coil of a radiogoniometer, or a rotating loop, is driven through suitable gearing by a D.C. motor.

The signal output after rectification is applied to the primary of the transformer T, the secondary of which is in the grid circuit of a valve that is normally biassed to cut-off point. This secondary winding is connected in such sense that the e.m.f. induced in it due to an increase of the D.C. primary current will reduce the negative bias on the valve grid, the

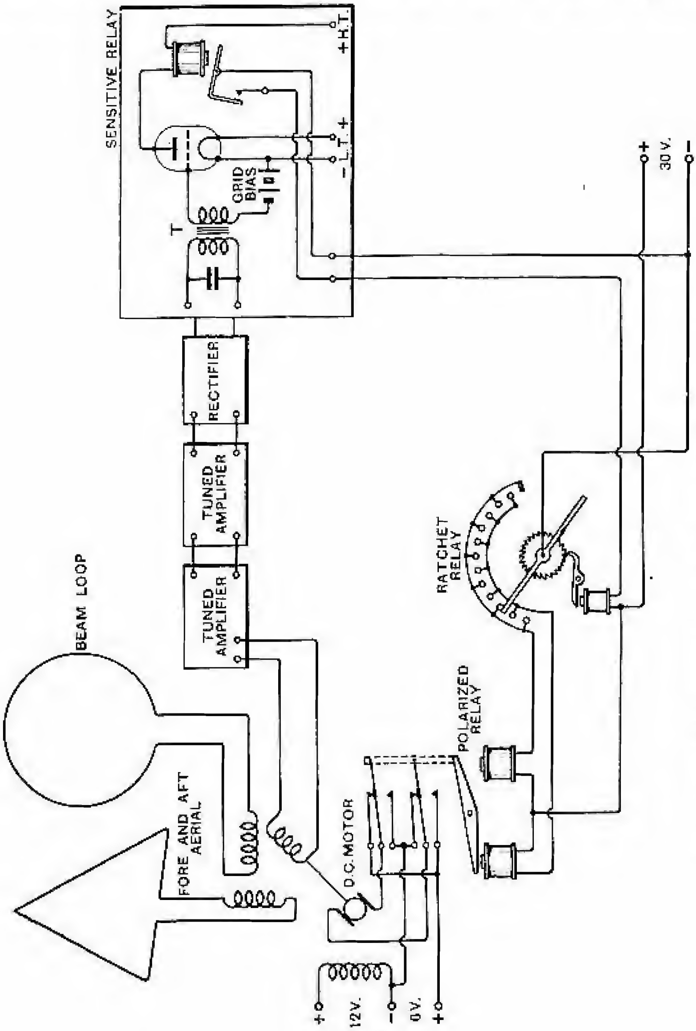


Fig. 528.—H.M. Signal School Automatic ("Hunting" Type) D.F.

resulting anode current operating the sensitive relay and "ratchet relay" shown. This last piece of apparatus reverses the D.C. motor drive each time it operates, and hence reverses the direction of movement of the loop whenever the signal increases. The direction finder accordingly hunts for and selects the loop position for minimum signal.

Another device of similar type is mentioned in (2501).

THE SIMON RADIOGUIDE

This apparatus employs a somewhat unconventional principle and provides a radio compass equipment in which there is not only visual indication of the on-course and off-course conditions, but the divergence from the course is shown in degrees up to a limiting arc of about 50° on either side.

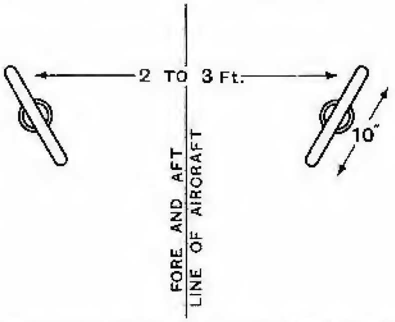


Fig. 529.—Twin Loops of the Simon Radioguide.

By means that are mentioned later, the direction of an incident signal relative to, say, the fore and aft line of an aircraft, can be measured and the apparatus thus becomes a direct reading direction finder, though the process is not fully automatic in the present stage of development of the system.

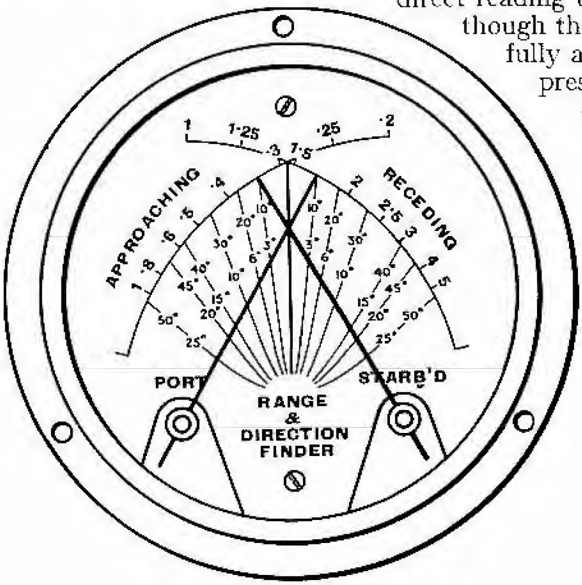


Fig. 530.—Scale and Pointers of the Simon Radioguide.

Principle of Operation. The circuit consists of two similar loop aerials, each of about 9 or 10 inches diameter, spaced a few feet apart along a line at right angles to the fore and aft line of the aircraft and arranged to have no mutual inductance. Each loop is situated so that its plane makes an angle of 30° with the fore and aft line, as in Fig. 529, and instead of the two e.m.f.'s being combined in some form of radiogoniometer or balancing circuit, they are separately amplified in twin superheterodyne receivers, the rectified outputs of which operate two D.C. milliammeters. These two meters are combined in such a way that their pointers intersect over a common scale, as shown in Fig. 530, and the point of intersection is made to indicate the relative bearing of the transmitter.

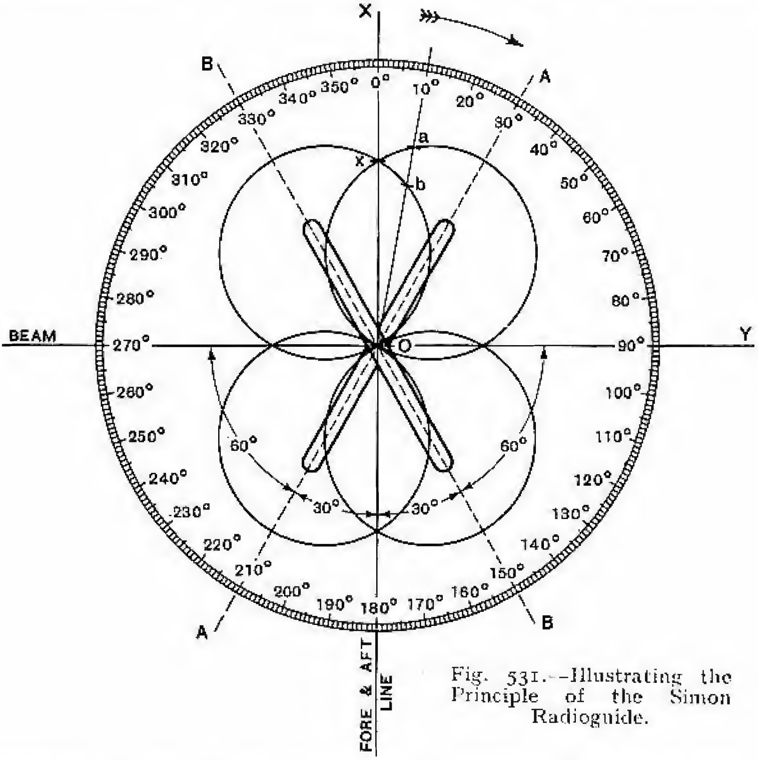


Fig. 531.—Illustrating the Principle of the Simon Radioguide.

In order to obtain such indication, it is necessary that the pointer intersection shall move progressively across the scale with increasing divergence of the aircraft from the homing course and it is this fact that is found to limit the useful operating arc for any given setting of the loops, and for the following reason.

In Fig. 531, AA and BB are the two similar loops, whose planes are each 30° from the centre line OX. The loop e.m.f.'s will therefore be equal for a wave incident along XO and the ratio of the AA e.m.f. to the BB e.m.f. will increase as the direction of incidence follows the arrow.

It should be noted that at XO each e.m.f. is equal to E_{max} cos 30°, where E_{max} is the loop e.m.f. for a signal in its plane, whilst at 10° towards the plane of AA, the AA e.m.f. is equal to E_{max} cos 20° and the BB e.m.f. to E_{max} cos 40°, and so on. The individual e.m.f.'s and their ratios may be tabulated thus :

Relative Bearing of Signal	AA e.m.f.		BB e.m.f.		Ratio
0°	E_{max} cos 30°	0·866	E_{max} cos 30°	0·866	1
10°	,, ,, 20°	0·940	,, ,, 40°	0·766	1·23
20°	,, ,, 10°	0·985	,, ,, 50°	0·643	1·53
30°	,, ,, 0°	1·000	,, ,, 60°	0·5	2·0
40°	,, ,, 10°	0·985	,, ,, 70°	0·342	2·88
45°	,, ,, 15°	0·966	,, ,, 75°	0·259	3·74
50°	,, ,, 20°	0·940	,, ,, 80°	0·174	5·4
55°	,, ,, 25°	0·906	,, ,, 85°	0·087	10·4
60°	,, ,, 30°	0·866	,, ,, 90°	0	Inf.

From this it will be seen that although the AA loop e.m.f. passes through its maximum and falls back to its starting value, the ratio of the two e.m.f.'s increases steadily up to about 50°, when it rapidly rises to infinity as the BB loop e.m.f. falls to zero.

The discrimination in the successive intersections will become very poor as the pointer of the BB loop indicator moves more slowly and ±50° is thus the limiting useful arc for a 60° angle between the loops.

Ambiguity. In addition to the 180° ambiguity inherent in any loop system, there is also a further source of ambiguity in the present case, which arises from reception of a signal along YO or its reciprocal, that is to say, on the beam.

For the YO direction, the angle between the loops is 120°, and if a set of tabulated data be prepared for this case, in the same way as has been done above, it will be found that the limiting angle is reached more rapidly than before because the zero direction for one or other of the loops occurs at 30° off the line YO. The 120° loop angle is thus more sensitive than the 60° angle, and in Fig. 530 the 0° to 25° angles have been marked on the same set of lines as has the 0° to 50° calibration for the previous case.

These calibrations may be used either for bearings of transmitters on or near the beam directions or, by altering the angle of the loops, for more accurate work ahead or astern.

The fore and aft ambiguity is avoided by the use of an open aerial, giving unilateral reception for sense determination, whilst the beam or 90° ambiguity may be settled by an inspection of the behaviour of the indicators on swinging the loops towards the bow or beam directions alternately, when the deflections will show which is the direction of maximum signal and hence of the transmitter.

Distance Measurement. A further use is made of the D.C. meters by marking a scale to show the proportional distance covered towards or away from the transmitter. This cannot conveniently be calibrated in miles but, in the case of approach, the receiver gain is set so that the pointer on the left-hand scale reads 1 when at some known distance, after which the increasing deflection indicates the proportion of this distance covered. Conversely, on flying away from a transmitter, the right-hand scale is used, and again the pointer is set at 1 for a known distance, after which the falling deflection indicates multiples of this distance.

Direction Finding. In using the apparatus for direction finding, the inability to measure a bearing that is 60° off the bow (or thereabouts) can be overcome by changing the bow angle between the loops from 60° to 120°, as mentioned above. The bearing then comes within the useful arc on the beam and can be read as a beam bearing.

Lining Up. The two receivers are designed to have linear response over the signal ratios for which the apparatus is intended to work, and the control panel provides switching whereby each amplifier can be connected to a common source of signal and balanced before being put into use, or at intervals during homing, if required.

Night Effect. It has been claimed that when this apparatus is in use for homing, it is to some extent free from polarization error when the aircraft is "on-course," in that each loop will be equally affected by the horizontally polarized ray that causes the error. That this is not the case, however, can be confirmed by reference to the set of graphs of Fig. 186, showing the effect of polarization error on the polar diagram of reception of a closed loop.

Suppose that at a certain instant, the combination of

A, B and C rays (page 205) is such as to produce a polar diagram as shown in Fig. 186 (*g*), where the minimum is approximately 60° anti-clockwise from the true direction. In such a case, the starboard loop of the apparatus in question would be almost in a position of minimum reception whereas the port loop would be receiving a comparatively large signal, and the ratio of the e.m.f.'s would be hopelessly in error.

In any case, it may be noted that it is never of any advantage for a radio compass system to be free of error when the aircraft is on-course, if it is liable to extensive errors when off-course, for in such a case a 20° error when the aircraft is 20° off-course may result in an on-course reading, so that no indication is of any value.

A description, with photographs of the equipment, is given in (3619) and its possible adaptation to Instrument Landing in (3614).

CHAPTER 17

FIELD AND NAUTICAL ASTRONOMY APPLIED TO D.F.

In this Chapter are described the solutions of a few problems of field and nautical astronomy, etc., a knowledge of which may, at any time, be of use to engineers engaged in the erection of direction finding or directional receiving stations and who may be called upon to lay out an aerial system in a given direction with considerable accuracy. Although the average D.F. station cannot be operated to within an accuracy of anything approaching one or two minutes of arc, there is no excuse for slipshod work in laying out the aerials with the subsequent introduction of an irritating element of doubt as to whether they are really North, South, East and West, or whether they are a quarter or a half a degree in error. A certain amount of familiarity with the use of the theodolite and similar instruments is assumed, and also with mathematical tables.

Position of Heavenly Bodies. At the beginning of Chapter 8 it was seen that the method of locating a point on the surface of the earth is by means of latitude and longitude, and a very similar process is adopted for the heavenly bodies. We know that actually the earth rotates about its axis once in approximately twenty-four hours, and that it takes an elliptical path round the sun once in a year. For many astronomical purposes, however, it is found simpler to suppose the earth to be still and all the remaining heavenly bodies moving, their relative positions being designated in the following way.

The earth appears to be at the centre of an infinitely large sphere, on which we see the heavenly bodies projected, and to the surface of which they appear to be attached. This infinite sphere, which is illustrated in Fig. 532, is called the **Celestial Concave.** Owing to the rotation of the earth the celestial concave, with the heavenly bodies, appears to turn once in twenty-four hours about a line joining the **Celestial North Pole** and the **Celestial South Pole,** which are the projections of the corresponding points on the surface of the earth. The projection of the earth's equator on the celestial concave is called the **Celestial Equator,** while lines drawn on the celestial concave through the poles at right angles to the celestial equator, like the meridians of longitude on the surface of the earth, are called **Hour Circles.** The hour circles rotate with the celestial concave.

Lines drawn on the celestial concave parallel to the celestial equator are called **Parallels of Declination.** They correspond to the parallels of latitude on the surface of the earth.

The position of the projection of any heavenly body on the celestial concave is specified by quoting the hour circle and the parallel of declination on which it appears to lie.

The hour circle which at any instant passes through the point directly overhead at the place of observation, the **Zenith,** coincides at that instant with the **Celestial Meridian** of that place. For any place of observation the celestial meridian is a fixed line. It is the line in which the vertical north-south plane through the place cuts the celestial concave.

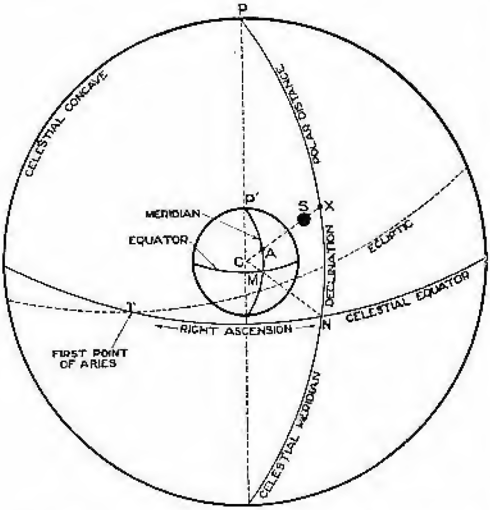


Fig. 532.—True Position and Geographical Position of Heavenly Bodies.

Distances on the celestial concave are expressed as the angles which they subtend at the centre of the concave.

The projections on the celestial concave and on the earth of any heavenly body are called respectively the **True Position** and the **Geographical Position** of the body. Thus, in Fig. 532, if S represents the body in space, X will be its true position and A its geographical position. The geographical position of a heavenly body, being the point where the body is directly overhead, is called the " **Sub-Solar Point** " when the sun is being considered, and the " **Sub-Lunar Point** " or the " **Sub-Stellar Point** " for the case of the moon or a star.

Ecliptic. This is the name given to the apparent annual path of the sun on the celestial concave, due to the annual revolution of the earth round the sun, so that if S had been the sun, the point X would have been on the ecliptic.

Declination. The equivalent of latitude on the celestial concave is called **Declination.** In Fig. 532 the arc MA is the latitude of the geographical position of the body S, and the arc NX on the celestial concave is the declination of its true position. From the Nautical Almanac can be found the declinations of the sun, moon, and principal planets and fixed stars, for any Greenwich Mean Time (see page 711) throughout each day.

Polar Distance. The co-latitude P′A of the point A, when referred to the celestial concave, is called the **North Polar Distance PX.**

Right Ascension. The equivalent of terrestrial longitude on the celestial concave is called **Right Ascension (R.A.).** It is the angle at the celestial pole, or the angular distance intercepted on the celestial equator, between the hour circle through the body and some standard hour circle. In measuring geographic longitudes we have to choose quite arbitrarily our starting point, which in practice is the meridian passing through Greenwich. In the same way we have to select an hour circle from which to measure right ascensions, but in this case a convenient starting point is indicated by Nature. In Fig. 533 is illustrated the orbit of the earth round the sun. It will be noted that the axis of the earth is not at right angles to the plane in which the earth's orbit lies. The plane drawn through the earth's equator is therefore tilted relatively to the plane of the earth's orbit, and they make with one another an angle of 23° 27′. Consequently, the sun as seen from the earth will appear to move round the celestial concave in a path the plane of which makes an angle of 23° 27′ with the celestial equator. As already mentioned, this path is called the ecliptic. It crosses the celestial equator at two points. The point at which the Sun in its motion along the ecliptic crosses the equator from south to north is called the **First Point of Aries** (the Ram), and is denoted by the symbol ♈ which represents conventionally the head and horns of the ram. It is the hour circle through ♈ which is taken as the starting point for the measurement of right ascensions. Thus, in

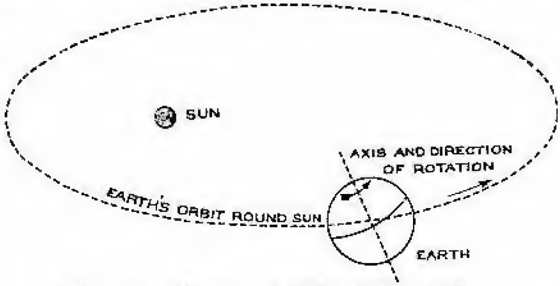


Fig. 533.—Movement of Earth Round Sun.

Fig. 532, the right ascension of the body S is the distance ♈ N expressed in degrees, or the angle ♈ PX.

Geographical longitudes are measured east or west of the meridian of Greenwich up to 180°. Right ascensions, however, are always measured eastward from the hour circle through ♈, from 0° to 360°. The angle between any two hour circles is a measure of the time which elapses between the passages of these circles across the meridian of a place on the earth. The earth's rotation causes the celestial concave apparently to turn through 360° in 24 hours, or through 15° in one hour, so that right ascensions can also be expressed in time, from 0 hours to 24 hours, and in practice this method is always adopted. The right ascensions of the sun, moon, principal planets and fixed stars, appears in the Nautical Almanac.

Sidereal Time. The earth rotates on its axis at a constant speed, and the period of time taken for one rotation, that is, the period of time between successive passages of a star across the meridian of any place, is a **Sidereal Day,** of 24 sidereal hours. Time expressed in this unit is known as **Sidereal Time.** Sidereal time is used extensively in astronomy, each sidereal day in the " sidereal almanac " being considered as beginning at the instant of the passage of ♈ across the meridian. The sidereal time at which any other point on the celestial concave crosses the meridian is therefore the same as the right ascension of that point, expressed in time.

Hour Angle. At any instant the angular distance on the equator or the angle at the pole, measured westwards, between the meridian of a place and the hour circle through a heavenly body, is called the **Hour Angle (H.A.),** of that body. Expressed in time, it is the time which has elapsed since the body was due south at the place. The local sidereal time is therefore equal to the H.A. of ♈. It is also equal to the R.A., at that instant, of the meridian of the place.

Apparent Solar Time. A Solar Day is the period of time which elapses between successive passages of the sun across the meridian of any place. Time expressed in this unit is known as **Apparent Solar Time.** It is the time shown by a sundial. It is generally referred to as **Apparent Time (A.T.).** Reckoned from noon it is the H.A. of the sun. Reckoned from the previous midnight it is the H.A. of the sun plus 12 hours. If, however, this should come to more than 24 hours, 24 hours must be subtracted from the result, since the time at any instant cannot be greater than 24 hours.

If the place considered is Greenwich, the apparent solar time is known as **Greenwich Apparent Time (G.A.T.).**

Owing to the earth's motion in its orbit, the sun is apparently moving on the celestial concave from west to east, that is, its R.A. is continually increasing. A solar day will consequently be longer than a sidereal day.

Owing to the varying speed of the earth in its orbit, the speed of the sun along the ecliptic will also vary. Because of this, and also because the sun is apparently moving in a path inclined to the plane of the equator, the apparent daily displacement of the sun towards the east, that is, its increase in right ascension, is not uniform, and hence the periods of time which elapse between successive passages of the sun across any meridian are not constant. Consequently, a clock cannot be regulated to keep apparent solar time.

Mean Time. For the sake of convenience, a mean solar day is taken as our standard. It is equal to the period which would elapse between the meridian passages of an imaginary **Mean Sun** which moved at a uniform rate round the celestial equator, instead of the ecliptic. Time expressed in this unit is known as **Mean Time.** The right ascension of the true position of the imaginary mean sun is called the **Right Ascension Mean Sun (R.A.M.S.).** To distinguish between this imaginary mean sun and the real sun, the latter is known as the **True Sun.**

Greenwich Mean Time (G.M.T.). This is the mean time of the meridian of Greenwich, commencing at midnight and reckoned throughout the 24 hours. Noon G.M.T. is the instant of passage of the mean sun across the meridian of Greenwich. Up to and including the year 1924, the above was known as **Civil Time** as distinct from G.M.T., which was then reckoned from noon instead of midnight. G.M.T. was altered to conform to Civil Time in 1925. It is, however, sometimes convenient to use the old method of reckoning mean time from noon. To distinguish this from time reckoned from midnight it is called "**Mean Astronomical Time**" **(M.A.T.).** If we are considering some particular place we speak of the **Mean Astronomical Time of Place (M.A.T.P.).**

Local Mean Time or Mean Time of Place (M.T.P.). Since the mean sun appears to make a complete revolution (360°) round the earth in the 24 hours of the mean solar day, it follows that at Greenwich mean noon, in a place in longitude, say, 15° East of Greenwich, the sun will already have passed the meridian 15/360ths = 1/24th of a day = 1 hour ago, and the M.T.P. will therefore be one hour fast on G.M.T. In the same way, places in longitudes west of Greenwich have their mean noon later than Greenwich and their mean time is accordingly slow on G.M.T.

Difference of Longitude, measured in degrees, minutes and seconds of arc, can be converted into Time measured in hours, minutes and seconds, by means of tables, or by using the following relationships :

Time = Arc
24 Hours = 360 Degrees
1 Hour = 15 Degrees
4 Minutes = 1 Degree
1 Minute = 15 Minutes
4 Seconds = 1 Minute
1 Second = 15 Seconds

Equation of Time. This is the difference at any instant between mean and apparent time, taken in the sense "mean minus apparent." It is therefore the correction which has to be added (algebraically) to *apparent* time, reckoned from midnight, to obtain *mean* time. These corrections are tabulated in Whitaker's Almanac.

In consequence of the introduction of wireless time signals, a navigator or surveyor now-a-days always knows G.M.T. The Unabridged Nautical Almanac therefore tabulates the values of the Equation of Time with the signs reversed, so that the tabulated figures are the corrections which have to be added to or subtracted from *mean* time to obtain *apparent* time.

In practice, however, it is not the apparent time, but the hour angle of the true sun, which is usually required. This is the apparent time reckoned from midnight, plus or minus 12 hours. To enable the H.A. of the true sun to be obtained in one operation, the actual values of the equation of time are not now tabulated in the Abridged Nautical Almanac, but instead there is tabulated a quantity *E*, which is 12 hours minus the equation of time. By adding *E* to *mean* time there is therefore obtained the *apparent* time reckoned from midnight, plus 12 hours. This addition of 12 hours alters the reckoning from midnight to noon. As has already been explained, the H.A. of the true sun is the apparent time reckoned from noon, so by adding *E* to M.T.P. the H.A. of the true sun is obtained. If the result should be greater than 24 hours, 24 hours must be deducted.

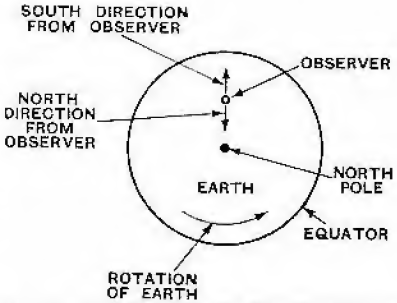
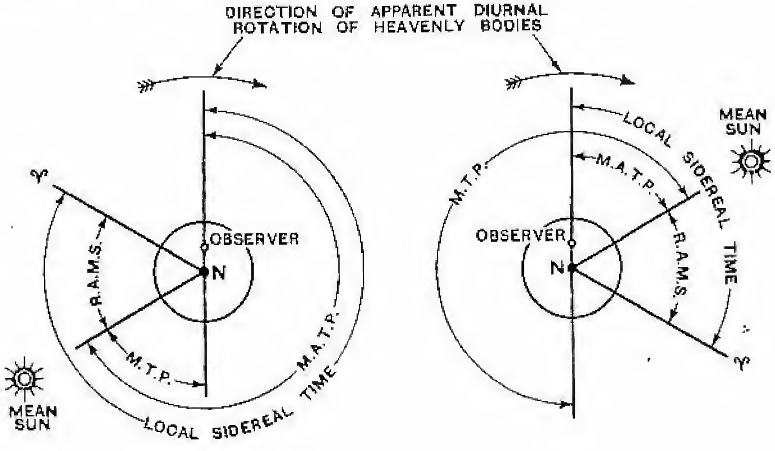


Fig. 534.—North and South Directions from an Observer on the Earth's Surface.

The different methods of tabulating the equation of time should be carefully noted.

Note Regarding Illustrations. In Fig. 535 (*a*) and (*b*), Fig. 541 and Fig. 544 it is necessary to show the position of the observer on the earth and the relative directions of certain heavenly bodies. Compared to the distance of the heavenly bodies, the size of the earth is completely negligible but it has to be drawn sufficiently large to show the observer and to indicate the north and south direction relative to him.



(a) (b)

Fig. 535.—Local Sidereal Time.

This has been done by imagining the reader to be looking down on the North Pole of the earth, the earth being represented by a small circle, the centre of which is the Pole, and the circumference the Equator. This is shown in Fig. 534 in which the observer and his north and south directions are marked.

In the other illustrations mentioned, it should be remembered that, so far as the bearings of heavenly bodies are concerned, the earth is a point and the observer is thus at the centre of the system.

In Fig. 534 the direction of rotation of the earth is indicated. The apparent diurnal rotation of the celestial concave is therefore in the opposite direction.

Local Sidereal Time. From Fig. 535 (*a*) and (*b*) it is seen that Local Sidereal Time=M.A.T.P.+R.A.M.S.

Since 24 hours make a complete day, the number expressing the time at some instant during a day, that is, the period which has elapsed since the beginning of the day, must be less than 24 hours. If M.A.T.P. and R.A.M.S. are not both less than 12 hours it may happen that their sum is greater than 24 hours. To obtain the sidereal time, that is, the period which has elapsed since the last transit of ♈ across the meridian, or since the beginning of the current sidereal day, it is then necessary to dednct 24 hours.

Let R.A.M.S. ± 12 hours be denoted by R, the plus sign being taken if R.A.M.S. is less than 12 hours, and the minus sign if R.A.M.S. is greater than 12 hours, so that R is never negative nor greater than 24. Then R.A.M.S. $= R \mp 12$ hours, where the negative sign is taken if R is greater than 12 hours, and the positive sign if R is less than 12 hours.

Also, M.A.T.P. = M.T.P. ± 12 hours, the plus sign being taken if M.T.P. is less than 12 hours, Fig. 535(*a*), and the minus sign if M.T.P. is greater than 12 hours, Fig. 535(*b*).

Then by substituting for M.A.T.P. and R.A.M.S. in the first equation, we obtain :

Local Sidereal Time = M.T.P. ± 12 hours $+ R \mp$ 12 hours.

Various cases arise but it can be shown that in every instance :—Local Sidereal Time = M.T.P. $+ R$ (less 24 hours if necessary). The values of R are tabulated in the Abridged Nautical Almanac.

Zenith Distance. In Fig. 536, S represents a heavenly body, and A and X its geographical and true positions respectively. Suppose B to be any other point on the earth, with corresponding position Z on the celestial concave. Then Z is called the **Zenith** of B, and the arc ZX, or the angle ZCX, is the **Zenith Distance** of X at the point B. The angular zenith distance of X expressed in circular measure (radians), and multiplied by the radius of the earth, is clearly the great circle distance between A and B. The constants by which the zenith distance, expressed in degrees, must be multiplied to give the great circle distance in either kilometres, nautical miles or statute miles, will be found on page 746.

Azimuth. In Chapter 8 we saw that the angle P′BA was the true bearing or azimuth of A at the place B. Similarly, when referred to the celestial concave, PZX, which is equal to P′BA, is the azimuth of X and may be expressed in degrees E. of of North, as in the case of the true bearing. It should be observed that the true position X, and the sub-solar or substellar point A, are in the same vertical plane ZXAC.

Hour Angle and Difference of Longitude. Knowing the hour angle of the sun at any given place, the difference of longitude between the geographical position of the sun (the sub-solar point) and the place, measured westward from the place from 0° to 360°, may be found at once by converting the hour angle to degrees (page 712).

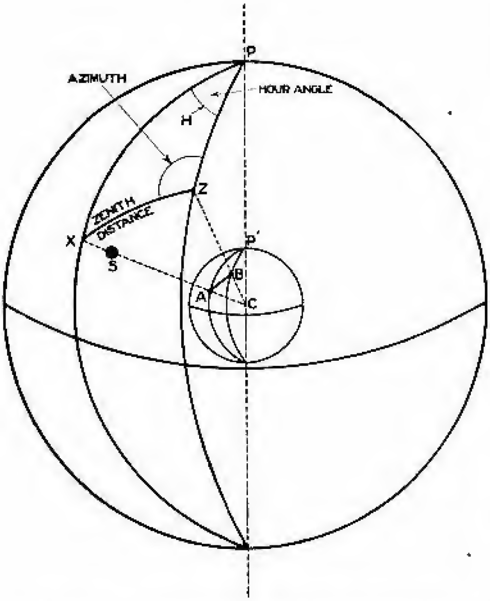


Fig. 536.—Azimuth, Zenith Distance and Hour Angle.

Greenwich Date (G.D.). In the almanacs, the tabular matter regarding the heavenly bodies is all given for G.M.T. Before referring to the tables of Equation of Time, R.A., etc., it is therefore necessary to convert the M.T.P. of any observation to G.M.T. by applying the correction for the difference of longitude expressed in time. It may also be necessary to alter the day of the month, as for instance in the case of an observation taken in New York at $21^h\ 00^m$ local standard time on September 9th. The meridian to which the local standard time used at New York is referred is 75° West, so that New York time is 75/15 or 5 hours slow on G.M.T. It is therefore necessary to add 5 hours to the local time to obtain G.M.T., so that the "Greenwich Date" is $02^h\ 00^m$ on September 10th.

Dates in Astronomical Calculations. In astronomical calculations, it is usual to write the time and date of an observation in the order year, month, day, hour, minute, second. Thus, $5^h\ 36^m\ 45^s$ on September 9th, 1936, would be written "1936, Sept., $9^d\ 05^h\ 36^m\ 45^s$." The date alone would be written "1936 Sept. 9," without the addition of "th."

METHODS OF FINDING THE DIRECTION OF TRUE NORTH

The methods of finding the direction of the meridian through the position selected for the D.F. aerial system are numerous, and it is an advantage to have as many as possible available, so that two or three of the most convenient may be used as a check one on the other, when extreme accuracy is demanded. Some of the methods require careful work with the theodolite or sextant, accurate timing of observations, corrections of the watch by means of a time signal and calculation in order to obtain the results; others are more simple. Thirteen methods are mentioned below, with short descriptions of the principles involved, whilst in the succeeding pages they are dealt with in greater detail, together with a number of worked examples.

In practical work it is strongly recommended that a diagram similar to those accompanying the various examples, be always drawn with the approximately correct values of the different angles involved. Such a diagram will enable the various steps in the calculation to be clearly followed, and will prevent mistakes arising from angles being taken with incorrect signs.

I. **Prismatic Compass.** (Page 722). In any but expert hands this is not a good method, and it is of no use for accurate work.

II. **Survey Map.** (Page 723). With ordinary care this gives results accurate to within 5 or 6 minutes of arc. It requires one or more Ordnance Survey or other reliable maps of the district. A theodolite or sextant is used, also a straightedge and a good protractor, but there is no calculation to be done.

Measurements of Azimuth of Heavenly Bodies

In the Almanacs are tabulated the Right Ascension or *R* and the Declination of the Mean Sun, the Right Ascensions and Declinations of the Moon, the four navigational planets Venus, Mars, Jupiter, and Saturn, and of a large number of the principal stars. From these data the azimuth of any of these bodies at any given time can be calculated. If, therefore, a careful measurement be taken of the bearing of some heavenly body, from a fixed point of reference visible from the site, and the exact time be noted at which the observation is made, it is only necessary to calculate what was the azimuth of the body at the instant, in order to find the direction of the meridian relative to the fixed point of reference.

III.	**Sun.**	(Page 725)	Fairly long Calculation.	Required: Theodolite, Nautical Almanac, Good Watch and Time Signal.
IV.	**Moon.**	(Page 727)		
V.	**Planet.**	(Page 732)		
VI.	**Star.**	(Page 732)		
VII.	**Pole Star.**	(Page 732)	Short Calculation.	

Observations of Meridian Passage of Heavenly Bodies

Since the earth rotates on its axis once in a little less than 24 hours, it follows that practically all the heavenly bodies will, at some time of the day or night, cross the meridian of the observer and, if not exactly overhead, must then be either due North or South. The instant at which this takes place is called the **Meridian Passage** or **Transit** of the body. In the case of the Sun, this is, of course, the time of apparent noon.

The approximate daily times of meridian passage of the Moon and the four navigational planets are tabulated in the Nautical Almanac for the meridian of Greenwich and can easily be accurately found for any body on any meridian, from other data given in the same book.

VIII.	**Sun**	(Page 734)	Short Calculation.	Required: Theodolite or Plumb Line, Nautical Almanac, Good Watch and Time Signal.
IX.	**Star.**	(Page 735)		
X.	**Star.**	(Page 738)	No Calculation.	
XI.	**Planet.**	(Page 739)	Short Calculation.	
XII.	**Moon.**	(Page 739)		
XIII.	**Pole Star.**	(Page 739)	No Calculation.	Required: Theodolite or Plumb Line and Watch.

The most convenient and most accurate way to observe a meridian passage is with a theodolite or transit, but an improvised method, in which a plumb line is used, is described on page 719 for use when no more elaborate instrument is available, or when extreme accuracy is not essential.

APPARATUS

The Theodolite. In finding the direction of true North accurately by the astronomical methods mentioned in this chapter, a **Theodolite** or else an **Engineer's Transit** is required. The latter instrument is very similar to the theodolite but is not fitted with a vertical circle for the measurement of zenithal angles. A **Sun-Head** should be provided for solar observations, and there must be provision for illuminating the cross wires of the telescope when working at night. In case there is no sun-head with the instrument, a piece of smoked glass *held at the eye-piece end*

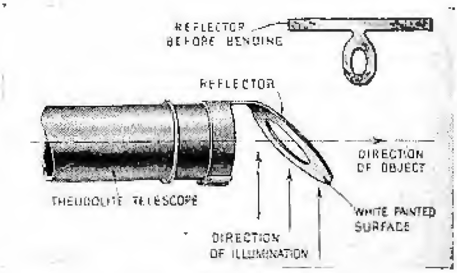


Fig. 537.—Easily Constructed Reflector for Illumination of Cross Wires of Theodolite or Transit.

of the telescope will enable the solar observations to be made, and a reflector for illuminating the cross wires can be made very simply as shown in Fig. 537. A piece of tin is cut and bent to form an annular reflector which clips on to the end of the telescope, the surface being painted white and illuminated by an electric torch fixed, or held, a foot or so distant.

It is assumed that the reader is able to set up and level a theodolite, to eliminate cross wire parallax and to check the vertical suspension of the telescope. Even if the instrument is said to be in good order it is unwise to start on a series of measurements without first checking the more important adjustments whilst, if it be handed over in really bad condition, the readjustment must be tackled methodically and it is a good plan to have a book of reference. All the information required on the subject is to be found in any good book on Surveying.

The Sextant. For the measurement of horizontal angles, when the objects are approximately at the same level, a **Nautical Sextant,** or else a **Box Sextant** can be used. A full account of the former will be found in " The Admiralty Manual of Navigation " and, of course, in many other nautical books. The Box Sextant is a more portable form of instrument and is described in the surveying books mentioned above. It is extremely simple in operation and can be read to a minute of arc.

Timing of Observations. In almost all astronomical work, the question of time is involved, and preparation should be made for the accurate timing of observations. For this purpose, any good watch is satisfactory, provided that means are available for checking the watch by a wireless time signal, or some other time signal, which is operated from an observatory. In the case of a visible time signal such as a falling ball, an assistant B is required who gives an audible signal to the observer A, who is following the seconds hand of the watch. At the instant of the signal, B gives the word and A notes and writes down the reading of the seconds hand, followed by the minutes and hours indicated by the watch. B should then be asked to check the minutes and hours, as it is usually in these, and not in the seconds, where mistakes are made. Care should be taken to make allowance for Summer Time, if it is in force. Confusion may also result if the minutes hand has been accidentally adjusted to be midway between two divisions, when the seconds hand is at 60. This should be altered before checking the watch.

If it be known some days before that the observations are to be made it is advisable to check the watch each day and to note the rate at which it is gaining or losing. Once this rate is known, and found to be steady, several hours may safely be allowed to elapse between the last time the watch was checked and the time of making the observation, a very simple calculation giving the error of the watch at the instant of observation. It is also advisable to check the watch at different times during the day, as the rate of a pocket watch may vary. This is especially the case if it be carried with the dial vertical in the daytime and laid flat at night.

Tables. The mathematical tables used in working out Great Circle Angles and Distances, or Azimuths in connection with astronomical observations, must be at least five figure ones and six figures are better. " Inman's Nautical Tables " will be found convenient in form. Tables of four figure logarithms or trigonometrical functions are not advisable.

A copy of the " Nautical Almanac " (Abridged) is required, although it is worth remembering that, for emergency use, " Whitaker's Almanack " contains all the essential information regarding the positions, etc. of the Sun, Moon, Planets and many stars, in a still more abridged form. Burdwood's or Blackburne's Azimuth Tables are useful when a large number of azimuths have to be found but are not essential for our purpose.

Foreign books corresponding to our Nautical Almanac are as follows :

COUNTRY	TITLE	DESIGNATION OF G.M.T.
U.S.A.	American Ephemeris	Greenwich Civil Time (G.C.T.)
France	Connaissance des Temps	Temps Civil de Greenwich
Germany	Berliner Jahrbuch	Weltzeit

Considerable reference is also now made to " Universal Time " or " U.T." which is the same as G.M.T. The French tend to use this more than they do " Temps Civil de Greenwich" and refer to it as Temps Universel which is contracted to T.U.

Plumb Line Observation of Meridian Passage. Fig. 538 illustrates a method of observing a meridian passage without the use of a theodolite or transit. A stake having been driven into the ground to mark the proposed position of the centre line of the aerial (or the mast in the case of a B-T station), some device is arranged to support a plumb line so that it hangs directly over the stake. The adjustment of the position of the plumb bob will be found quite simple if the line is suspended from a pole with stays attached, enabling the top to be pulled over to the correct position. The length of the line may have to be 15 or 20 feet when the body is high in the sky, since the accuracy of the method depends upon the distance between the observer and the line, and for this reason it is impossible to use it when the body is near the zenith. Thick thread is suitable for the line, and during a light breeze a fairly heavy bob suspended in a bucket of water will prevent the line from swaying.

Some form of movable " sight " is now required, through which the observer can follow the apparent movement of the body. For this purpose a small table is constructed, as shown, supported by two pointed stakes. These are driven into the ground so as to fix the table in the best position for the observation, the surface being levelled with a spirit level. A convenient form of " sight " is shown in the figure, and can be made from the glass of a photographic plate fixed to a wooden base. On one side of the glass is pasted a sheet of brown paper with a vertical slit about $\frac{1}{32}$ inch wide, and the other side is left clear for night work and is smoked for solar observations. 'It will be found better to have half the glass smoked and half clear when taking a meridian passage of the sun so that there will be one section of the slit through which the sun can be observed and another clear section for fixing the position of the distant stake. At night, the plumb line can be illuminated to render it visible.

On pages 734 onwards will be found the methods of calculating the time of meridian passage of the Sun, Moon, Planets, Polaris and other stars, together with the method of making allowance for the semi-diameter of the Sun and Moon when observation is made of the side or limb of the disc.

A minute or two before the time of meridian passage, the observer takes up a prone position on the ground behind the level table, convenient for making the observation. He then moves the sight slowly, keeping it always in such a position that the plumb line just eclipses the star, or bisects the sun's disc, as the case may be. An assistant holds the watch and gives the signal at the time previously calculated, the observer then fixes the sight on the table with a clamp or pins, the sight and the plumb line being now in the meridian.

A plumb line can, of course, be used in an observation of an azimuth, but in that case a sextant will be necessary to lay off the direction of the meridian later.

Marking Direction of True North. Having found the direction of the meridian by any of the methods mentioned here, it is as well to mark it by means of two fairly substantial wooden stakes, painted white. One may be short and with a nail in the top for locating the plumb bob of the theodolite for future measurements, and both may with advantage be concreted. If this is not done, they are almost bound to be moved accidentally, sooner or later. Tall posts should not be used if there are animals grazing on the site as they will be used for rubbing posts and probably displaced.

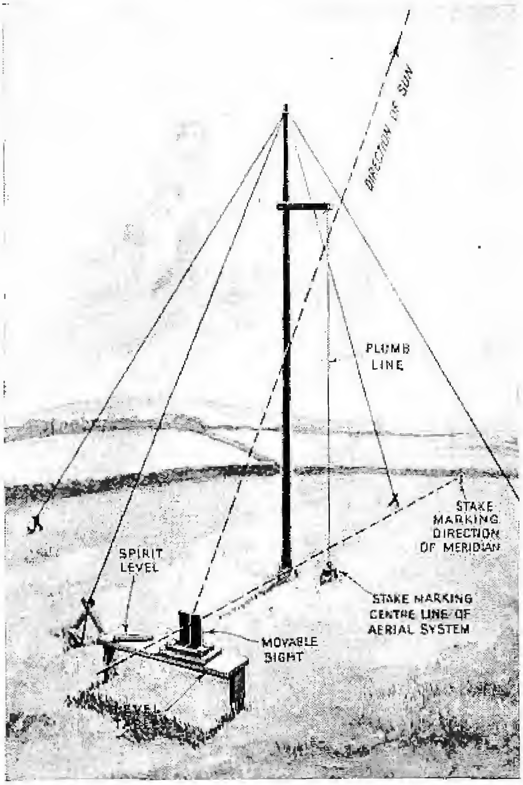

DIRECTION OF SUN
PLUMB LINE
STAKE MARKING DIRECTION OF MERIDIAN
SPIRIT LEVEL
STAKE MARKING CENTRE LINE OF AERIAL SYSTEM
MOVABLE SIGHT
LEVEL TABLE

Fig. 538.—Observation of Meridian Passage without Special Instruments.

Precision. The care to be taken in fixing a stake to mark the direction of true North, in locating the plumb bob of a theodolite or in laying out an aerial system after the direction of the centre line has been decided upon, can be judged by bearing in mind that at a distance of 57·3 feet from the observer, a transverse length of 1 foot subtends an angle of 1 degree, from which it follows that *at a distance of 95½ yards, a lateral error of 1 inch introduces an error of 1 minute of arc.*

Method I. Prismatic Compass. Familiarity with the use of the prismatic compass is assumed, and the way in which it may be adapted to find the direction of the meridian in the case of the site of a D.F. station will present itself to the reader after noting the foregoing remarks on the same subject. The correction for magnetic variation can be found from Admiralty Charts or Ordnance Surveys, and it should be noted that the variation is not a constant for any given place, but the necessary correction for the annual change is generally given on the chart or map. It is advisable to use as recent an issue as possible, and not to extrapolate more than necessary when making this correction.

It is necessary to make certain that no iron or steel objects are brought near the compass during the time the readings are being taken, knives, keys, etc., being removed from the

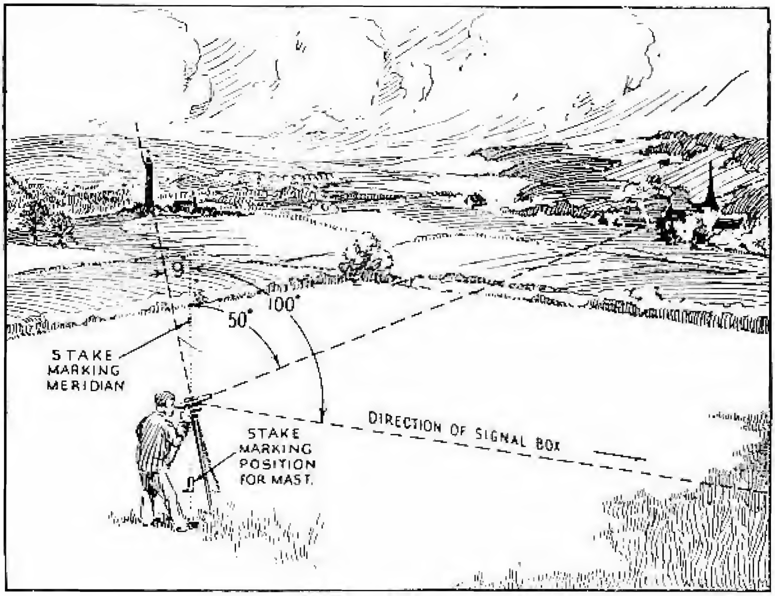


Fig. 539.—Determination of Direction of North from Bearings Obtained from a Map.

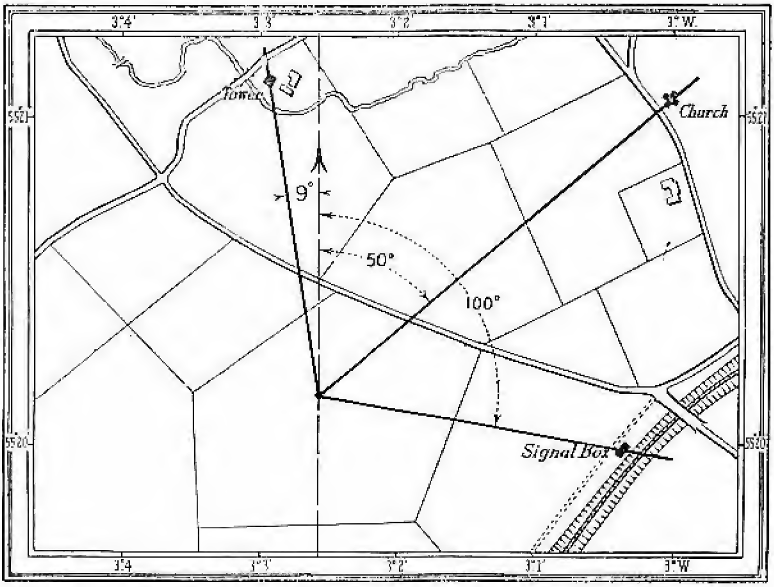


Fig. 540.—Map of District (Imaginary) shown in Fig. 539.

observer's pockets, and also care should be taken to ensure that the instrument is in good order and not sticking at all. Unless complete confidence can be placed in the compass to be used, this method of finding the direction of true North should not be adopted where any other is possible.

The compass is, of course, particularly well adapted to rapid orientation of an aerial system when accuracy is not of great importance.

Method II. Survey Map. In this method, a reliable map of the district is procured, which has the meridians of longitude shown, and on the map is fixed the exact position of the D.F. station. Bearings are now measured on the map between the meridian through the position of the site, and the directions of various conspicuous distant objects, such as churches, towers, etc., and these are reproduced on the site by means of a theodolite or sextant, and the direction of the meridian thereby found.

It should be borne in mind that the available maps of parts of the world in which it may be necessary to erect D.F. stations are by no means as accurate as the ones we are accustomed to use in the British Isles, and a lack of conspicuous objects or low visibility also conduce to bad results. The method has the advantages that it is not necessary to have a clear view of the sky, there are no calculations to be made, and a theodolite is not essential. Whilst it is more convenient to use a theodolite, a sextant is quite satisfactory.

Suppose Fig. 539 shows a view of the site chosen for the station. It is found that there are three conspicuous objects which can be seen from the position chosen for the mast, all of which are likely to be shown on an Ordnance Survey. Fig. 540 is a rough representation of the map of the district shown in Fig. 539. (The latitude and longitude have been chosen at random and the map does not represent any real place.)

On the map are marked the objects mentioned above, these being a tower, a church and a signal box. It may often be necessary to obtain several maps in order to include all the objects selected for bearings and in this case it is better to pin them out on a flat table rather than to paste them together, as this is not easy to do and may ruin the maps.

The position of the proposed mast is then marked on the map, and joined by straight lines to each of the objects. It is now necessary to fix the meridian through the station and for this purpose only those maps can be used which have either the meridians drawn, or a marginal scale of longitude, as in the map illustrated in Fig. 540. As already pointed out on page 281, the meridians are very rarely found to be parallel to the margins of the Ordnance Survey map, and if some other sort of map be used in which the meridians are not definitely shown, *it should never be assumed that the boundaries of the maps are meridians or parallels.*

A line having been drawn to indicate the direction of North, the bearings of the objects selected are measured off on the map. Having driven a stake into the ground to mark the position for the mast, the theodolite is set up so that its plumb bob hangs over the centre of this stake or, if a sextant is being used, it must be held vertically over the stake whilst readings are being taken. A distant stake is next placed in such a direction that bearings of the objects from this stake coincide with the bearings of the objects from North, as found on the map. In other words, the two stakes mark the direction of the meridian, the process being illustrated in Fig. 539.

This method is accurate to within 5′ of arc under favourable conditions, but there are certain precautions to be taken. If the objects on which bearings are taken are nearer than about a mile, errors are likely to occur owing to the inability to locate accurately on the chart the position of the mast. These errors are mentioned under "Precision" on page 721.

Method III. Sun's Azimuth. In this method of finding the direction of North, the horizontal angle between the sun and some fixed point of reference, which is fairly conspicuous, is measured and the time of the observation is accurately noted.

A calculation is then made to find out what was the azimuth of the sun at the instant the observation was made, and a simple process of addition or subtraction of angles will give the true bearing of the point of reference, and hence the direction of true North.

Assuming the theodolite has been located accurately over the proposed site for the centre line of the aerial system, the instrument is levelled and an observation made of the point chosen for the fixed point of reference. The reading of the horizontal scale when the telescope is in this position is noted. The telescope is now fitted with the sun-head and adjusted until the sun's disc is visible on one side of the field of the instrument and is approaching the centre. At the instant of contact of the sun with the vertical cross wire of the telescope a signal is given to an assistant with a watch, who notes the time to the nearest second; and similarly, when the opposite limb of the sun is just leaving the cross wire, the time is again taken and noted, care being taken not to move the instrument between the two readings. The reading on the horizontal scale is noted. The difference between this reading and the previous one gives the horizontal angular position of the telescope relative to the fixed point of reference, this corresponding to the angle subtended at the site by the point of reference and the centre of the sun at the time half-way between the two times at which the observations were made. This completes one set of readings, but additional ones should be taken and worked out for checking purposes.

Example. On September 10th, 1936, in latitude 51° 43′ 45″ North and longitude 0° 28′ 37″ East, observation were taken of the sun's horizontal bearing from a fixed point of reference, the times of the first and second contacts being $11^h\ 22^m\ 20^s$ and $11^h\ 24^m\ 35\frac{1}{2}^s$ a.m. by watch, and the measured bearing of the point of reference from the sun 130° 10′ in the anti-clockwise direction. The error of the watch was $58^m\ 47^s$ fast on G.M.T. It is required to find the true bearing of the point of reference, and hence the direction of the meridian at the place. The work may be set out as follows :

Date : 1936, September 10.

Latitude	51°	43′	45″ N.		
Longitude	0°	28′	37″ E. = 1^m 54^s E.		
Error of watch	58^m	47^s	fast on G.M.T.		
Watch (first contact)	11^h	22^m	20^s		
Watch (second contact)	11	24	36		
Watch (Mean of above)	11	23	28	September 10	(1)
Watch fast		58	47		(2)
G.M.T. and G.D.	10	24	41	September 10	(3)
Longitude		1	54	East	(4)
M.T.P.	10	26	35		(5)
E.	12	03	02		(6)
H.A. of Sun	22^h	29^m	37^s = 337° 24′ 15″	west of south	(7)
Diff. Long. between sub-solar point and place	22°	35′	45″	Sun east of place	(8)
Declination of sun = Lat. of sub-solar point	4°	56′	03″	North	(9)

The azimuth of the centre of the sun, or of the sub-solar point, is now calculated in the same way as any other great circle bearing (page 747), or it may be taken from Burdwood's Azimuth Tables to the nearest tenth of a degree (see page 744 for an example).

In this case, the azimuth is 150° 10′ east of north. Having found the azimuth by one of these methods, proceed as follows :

Azimuth of sun	150°	10′	E. of N., *i.e.*, clockwise.
Measured bearing of point of reference from sun	130°	10′	in anti-clockwise direction.
True bearing of point of reference	20°	00′	East of North.

Explanatory Notes on Above Example.

(1). Write down the time by watch, and date, of observed bearing of the point of reference from the centre of the sun's disc. This is the mean of the times of first and second contacts.

(2). Write down the error of the watch.

(3). Subtract watch error if fast, add if slow, giving Greenwich Mean Time and Date.

(4). Write down the longitude of the place converted into time (see page 712).

(5). For longitude East, add (4) and (3); for longitude West, subtract (4) from (3). This gives Mean Time of Place.

(6). From the Abridged Nautical Almanac take out the value of E for the Greenwich Mean Time and Date. (See page 712).

(7). Add (6) to (5). This gives the Hour Angle, expressed in time, of the sun at the time of the observation. Convert from time to arc.

(8). The Hour Angle is the difference of longitude between the place and the sub-solar point. If greater than 180°, subtract from 360° and write as longitude East of Place.

(9). Take from the Almanac the Declination of the Sun for the G.M.T. and G.D. (See definition, page 708).

Method IV. Moon's Azimuth. The operations to be carried out in measuring the bearing of the moon from a point of reference on the site, are very much the same as those already described in the case of the sun. The chief differences are that, except at full moon, only one limb can be used and allowance must be made for the semi-diameter, the value of which is tabulated in the Nautical Almanac for each day. The allowance for semi-diameter varies with the moon's altitude, which should be measured when the observation is made. If a transit without a vertical scale is being used, the altitude can be estimated sufficiently accurately up to about 45° since the correction is very small. For greater altitudes the value can easily be calculated by finding the great circle angular distance d between the observer and the geographical position of the moon (see page 747).

Altitude = $(90° - d)$.

It is an advantage, though not essential, to have the cross wires illuminated, provision must be made for illuminating the point of reference and an electric torch or a lamp of some kind is required to read the theodolite scales and the watch.

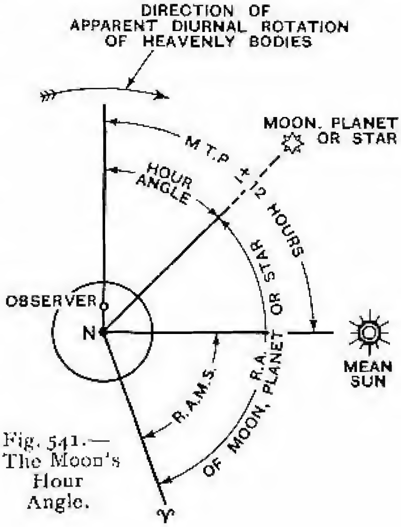


Fig. 541.—The Moon's Hour Angle.

The principle involved will be easily understood from what has already been said in the introduction to this chapter, and is illustrated in Fig. 541. (See Fig. 534 and explanatory section on page 713).

From this diagram we have :

H.A. Moon = R.A.M.S. + M.T.P. ± 12 hours − R.A. Moon.

But R.A.M.S. ± 12 hours = R (see page 714).

$\therefore$ H.A. Moon = M.T.P. + R − R.A. Moon ± 24 hours if necessary.

The H.A. Moon is the required difference in longitude between the place and the sub-lunar point.

The Declination of the moon gives the latitude of the sub-lunar point.

From these data the azimuth of the moon can be calculated.

Example. On September 23rd, 1936, in latitude 51° 38′ 12″ North and longitude 0° 18′ 00″ East, the bearing of a fixed point of reference from the limb of the moon (first quarter) was observed to be 162° 57′ in the anti-clockwise direction, and the approximate altitude of the moon was 15°. The watch time of the observation was $17^h\ 26^m\ 34^s$, and the error of the watch was 9 seconds *fast* on G.M.T. It is required to find the true bearing of the point of reference, and hence the direction of true North. The work may be set out as follows :

Date : 1936, September 23.

Latitude	51°	38′	12″ N.		
Longitude	0°	18′	00″ E. = $1^m\ 12^s$ E.		
Error of watch	09^s fast on G.M.T.				
Watch	17^h	26^m	34^s	September 23	(1)
Watch fast			09		(2)
G.M.T. and G.D.	17	26	25	September 23	(3)
Longitude		01	12	East	(4)
M.T.P.	17	27	37		(5)
R	00	09	31		(6)
	17	37	08		(7)
R.A. of moon	17	52	16		(8)
H.A. of moon .. *minus*	00	15	08	West of south	(9)
	24	00	00		
H.A. of moon	23^h	44^m	52^s	West of south	(10)
	= 00^h	15^m	08^s	= 03° 47′ 00″ East of south	(11)

This is the difference of longitude between the sub-lunar point and the place.

Declination of moon=Lat. of sub-lunar point .. } 23° 28′ 27″ South (12)

The azimuth of the centre of the moon, or of the sub-lunar point, is now calculated in the same was as any other great circle bearing (page 747), or it may be taken from Burdwood's Azimuth Tables to the nearest tenth of a degree (see page 743 for an example). In this case the azimuth is 176° 25′ east of north.

Having found the azimuth of the centre of the moon by one of these methods, proceed as follows :

The observed anti-clockwise bearing of the point of reference was from the western (right-hand) limb of the moon, not from the moon's centre. It is therefore necessary to subtract the angular value of the moon's semi-diameter in azimuth from this observed bearing to obtain the anti-clockwise bearing of the point of reference from the moon's centre. The actual values of the moon's semi-diameter are given in the Nautical Almanac.

When the moon is very near the horizon, the actual tabulated value of the semi-diameter is to be used, but when appreciably above the horizon a correction has to be applied to the tabulated semi-diameter for the reason apparent from Fig. 542.

If MM be the moon and HH the horizon of the observer O, NON will be the horizontal angle subtended by the moon's diameter at O and the angle will not greatly change for low altitudes. If, however, the moon be at the position mm, its disc will clearly subtend a much larger horizontal angle at O, as indicated, and the angular measure of its semi-diameter in azimuth will accordingly be increased.

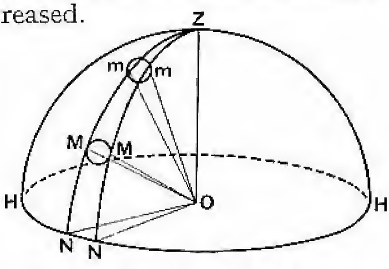


Fig. 542.—Variation, with Altitude, of the Angular Value in Azimuth of the Moon's Semi-Diameter.

The correct value for the difference in azimuth between either limb of the moon and the centre, is obtained by multiplying the tabulated semi-diameter by the secant of the altitude, this being the angle MON or mON for the two positions illustrated.

The tabulated semi-diameter of the moon, for

September 23^{d} 17^{h} 30^{m} is 15′·1. The altitude of the moon at the time of observation was 15°.

The difference in azimuth between the limb of the moon and its centre was then : $15'{\cdot}1 \times \sec. 15° = 15'{\cdot}1 \times 1{\cdot}035 = 15'{\cdot}6$, say 16′.

We have, therefore :

Azimuth of moon's centre ..	176° 25′ E. of N., *i.e.*, clockwise.	
Measured bearing of point of reference from western limb of moon	162° 57′ in anti-clockwise direction.	
Semi-diameter in azimuth ..	16′	(13)
Bearing of point of reference from centre of moon ..	162° 41′ in anti-clockwise direction.	
True bearing of point of reference	13° 44′ East of North.	

Explanatory Notes on Above Example

(1). Write down the time by watch, and date, of observed bearing of the point of reference from the Moon's limb.

(2). Write down the error of the watch.

(3). Subtract watch error if fast, add if slow, giving Greenwich Mean Time and Date.

(4) Write down the longitude of the place converted into time. (See page 712).

(5). For longitude East, add (4) and (3) ; for longitude West, subtract (4) from (3). This gives Mean Time of Place.

(6). From the Abridged Nautical Almanac take out the value of R for the Greenwich Mean Time and Date. (See page 714).

(7). Add (5) and (6).

(8). Take from the almanac the Right Ascension of the Moon for the G.M.T. and G.D. (see definition, page 709).

(9). Subtract (8) from (7). This gives the Hour Angle, expressed in time, of the Moon at the time of the observation, measured from south towards west.

(10). 24 hours are added to the negative angle in (9), to convert it to a positive angle.

(11). Hour Angle is the difference of longitude between the place and the sub-lunar point. If greater than 24 hours, subtract 24 hours and write as longitude West of place. Convert from time to arc.

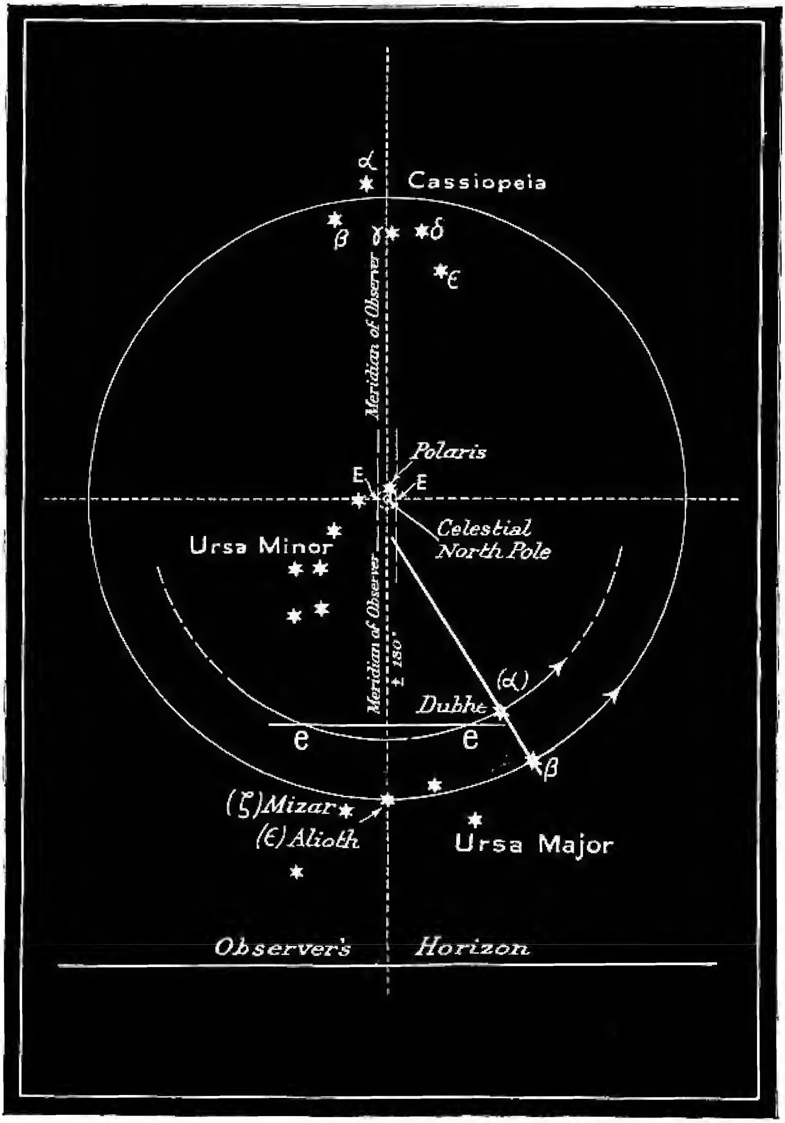


Fig. 543.—Northern Constellations and their Relation to the Pole Star.

(12). Take from the almanac the Declination of the moon for the G.M.T. and G.D. (see definition, page 708).

(13). Since we are only working to the nearest minute, there is no need to make correction for the effect known as the "Augmentation of Moon's Semi-diameter." This correction is never greater than 18 seconds of arc.

Method V. Azimuth of a Planet. If we employ one of the four navigational planets, instead of the moon, the method is identical with Method IV, except that as the planet shows no appreciable disc in a theodolite telescope, there is only one contact with the cross wire. It is essential, in this case, to have illuminated cross wires.

Method VI. Azimuth of a Star. The case of a star is just the same as a planet, but the R.A. and Declinations of stars are changing so slowly that they are only tabulated in the Nautical Almanac every month.

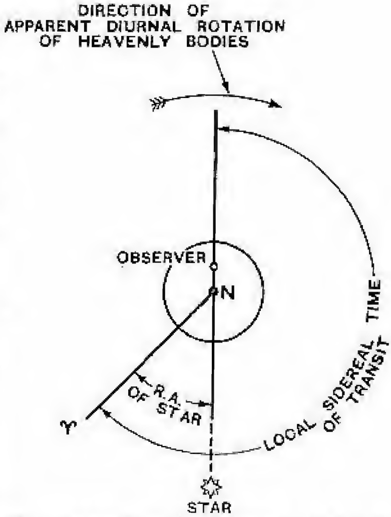

DIRECTION OF APPARENT DIURNAL ROTATION OF HEAVENLY BODIES
OBSERVER
N
TIME
LOCAL SIDEREAL TIME OF TRANSIT
R.A. OF STAR
♈
STAR

Fig. 544.—Meridian Passage of a Star (Star Shown in Inferior Transit).

Method VII. Azimuth of the Pole Star (Using the Pole Star Azimuth Table in the Abridged Nautical Almanac). Fig. 543 shows a star map from which it will be seen that if a straight line be drawn through the two stars β and α (the "pointers") of Ursa Major (The Great Bear or Plough), this line passes close to a fairly bright star of the constellation Ursa Minor. This star is Polaris. The true position of Polaris is popularly supposed to be at the Celestial North Pole, but this is not the case. The Polar Distance of Polaris is actually about 1°, and so it appears to move in a small circle about the pole (Fig. 543). There must be two instants during each rotation, when Polaris is due North, namely, when it is vertically above or below the pole, and hence on the meridian of the observer, or the meridian ± 180°, and the method whereby this may be used to find the direction of North is described on page 739. In the Abridged Nautical Almanac, however, there is a table giving the azimuth of Polaris, to the nearest tenth of a degree, for each hour of Local

Sidereal Time and this forms a shorter method than the previous two for finding the direction of the meridian. A more extensive table, giving the azimuths of Polaris to the nearest tenth of a minute of arc for each ten minutes of Sidereal Time, is given in the Unabridged Nautical Almanac.

Example. On November 25th, 1936, in latitude 51° 07′ 30″ North and longitude 3° 01′ 15″ West, the bearing of a fixed point of reference from the Pole Star was observed to be 4° 13′ in the anti-clockwise direction. The watch time of the observation was $02^h\ 15^m\ 17^s$, and the error of the watch was 19 seconds fast on G.M.T. It is required to find the Local Sidereal Time and the Azimuth of Polaris, and hence the direction of True North. The work may be set out as follows :

Date : 1936, November 25.

Latitude	51° 07′ 30″ N.		
Longitude	3° 01′ 15″ W. = $12^m\ 05^s$ W.		
Error of watch	19^s fast on G.M.T.		
Watch	$02^h\ 15^m\ 17^s$	November 25.	(1)
Watch fast	19		(2)
G.M.T. and G.D.	02 14 58	November 25.	(3)
Longitude	12 05	West.	(4)
M.T.P.	02 02 53		(5)
R.	04 15 24		(6)
Local Sidereal Time	$06^h\ 18^m\ 17^s$		(7)
Azimuth of Polaris	1°·5 West of North.		(8)
	=358° 30′ E. of N. *i.e.*, clockwise.		
Measured bearing of point of reference from Polaris	4° 13′ in anti-clockwise direction.		
True bearing of point of reference	354° 17′		

Explanatory Notes on Above Example.

(1). Write down the time by watch, and the date, of the observed bearing of the point of reference from Polaris.

(2) to (6). The same as the corresponding items on page 728.

(7). Add (5) to (6). This gives the Local Sidereal Time (see page 713).

(8). Take from the Abridged Nautical Almanac the azimuth of Polaris for the given Local Sidereal Time and latitude.

Method VIII. Sun's Meridian Passage. In this method, it is first necessary to calculate the G.M.T. corresponding to the instant of apparent noon at the place, and the way to do this will be found in the example which follows. Shortly before noon, the theodolite is carefully levelled, the sun-head fitted and the telescope directed to the sun. The position of the sun is then followed by the observer who slowly rotates the telescope horizontally, keeping the sun's disc bisected by the vertical cross wire, until the assistant gives the signal for apparent noon. At this instant the observer ceases to move the telescope, which is therefore now in the vertical plane of the meridian.

Since, however, it is difficult to estimate when the vertical cross wire exactly bisects the sun's disc, it is preferable to make allowance for the semi-diameter of the sun and to observe one limb. If this be done, then after the signal for noon and after writing down the scale reading, the telescope must be moved forward or backward, as required, through an angle equal to the semi-diameter, the value of which will be found in the Nautical Almanac, corrected for altitude in the same way as described in the case of the moon on page 729. Immediately this correction has been made, a stake should be driven in to mark the direction of the meridian.

On page 719 is described a method of observing the meridian passage without the use of a theodolite.

Example. Suppose that a D.F. station has to be erected on Robben Island (Table Bay) in longitude 18° 21′ 00″ E. and that on February 15th, 1936, it is required to find the time of apparent noon at that place in terms of G.M.T. The watch is nominally reading South African Union Time, which is 2 hours fast on G.M.T., but it has an error which makes it $2^h\ 03^m\ 17^s$ fast on G.M.T. The work may be set out as follows :

Date : 1936, February 15.

Longitude..	18°	21′	00″	E.=$1^h\ 13^m\ 24^s$ E.	
Error of watch	2^h	03^m	17^s	fast on G.M.T.	
A.T.P.	12^h	00^m	00^s	February 15.	(1)
Longitude..	1	13	24	East.	(2)
G.A.T. and G.D.	10	46	36	February 15.	(3)
	12	00	00		(4)
	22	46	36		
E.	11	45	40		(5)

G.M.T.	11 00 56	(6)
Watch fast	2 03 17	(7)
Watch reading for local noon	$13^{h}\ 04^{m}\ 13^{s}$	(8)

Explanatory Notes on Above Example.

(1). Write down the apparent time which it is required to convert to G.M.T., in this case, noon.

(2). Write down the longitude of the place converted into time (see page 712).

(3). For longitude West of Greenwich, add (2) and (1) ; for longitude East, subtract (2) from (1). This gives the Greenwich Apparent Time and Date.

(4). Add 12 hours, to allow for the 12 hours in *E*. (see page 712).

(5). Take from the Abridged Nautical Almanac the value of *E*. for the Greenwich Date and Apparent Time.

(6). Subtract *E*. This is equivalent to adding the Equation of Time, and gives the G.M.T. of local apparent noon.

(7). Write down the error of the watch.

(8). Add (7) and (6) if watch is fast on G.M.T. ; subtract (7) from (6) if slow. This gives the watch time corresponding to apparent noon.

Method IX. Meridian Passage of a Star. The advantage of employing the sun for observations of meridian passage is that one is able to work under rather better conditions than at night, but the method necessitates a clear sky at noon and if any slip be made or a check reading required a delay of 24 hours ensues. It is thus desirable to be in a position to calculate the time of meridian passage of any of the stars, the Right Ascensions of which are tabulated in the Nautical Almanac.

Now, at the instant of meridian passage of a star, the R.A. of the star must be the same as the local sidereal time at that instant. Fig. 544. But it was seen on page 713 that :

Local Sidereal Time=M.T.P.+R−24 hours if necessary, or M.T.P.=Local Sidereal Time−R+24 hours if necessary.

It is therefore only necessary to take out the R.A. of the star from the Almanac, subtract R, make allowance for the longitude of the place converted to time and the result is the G.M.T. of transit.

Since the R.A. of the stars vary very slightly, they are only tabulated for every month. On the other hand, R is changing at the rate of some minutes per day, and as the G.M.T. of transit is not known, it is impossible to choose the appropriate *R*. A preliminary calculation is therefore made, using *R* for Greenwich noon and this gives an approximate value for Greenwich date for which *R* can be taken out again and a final calculation made that will give a more accurate G.M.T. of transit.

Example. On February 10th, 1936, in longitude 14° 36′ 15″ East, it is required to find the time of meridian transit of Sirius (Alpha Canis Majoris). The work may be set out as follows:

Date: 1936, February 10.

Longitude..	14° 36′ 15″	E. = $0^h\ 58^m\ 25^s$ E.	
R.A. of Sirius	$06^h\ 42^m\ 22^s$		(1)
R.	09 17 36		(2)
	−02 35 14		(3)
	24 00 00		(4)
Approx. M.T.P. of transit	21 24 46	February 10.	(5)
Longitude..	00 58 25	East.	(6)
Approx. G.M.T. of transit	$20^h\ 26^m\ 21^s$	February 10.	(7)
R.A. of Sirius	$06^h\ 42^m\ 22^s$		
R.	09 18 59		(8)
	−02 36 37		
	24 00 00		
M.T.P. of transit.. ..	21 23 23	February 10.	
Longitude..	00 58 25	East.	
G.M.T. of transit.. ..	$20^h\ 24^m\ 58^s$	February 10.	

Explanatory Notes on Above Example.

(1). Take from the Abridged Nautical Almanac the Right Ascension of Sirius for February.

(2). From the Abridged Nautical Almanac take out the value of *R* for Greenwich noon on February 10th.

(3). Subtract (2) from (1).

(4). Add 24 hours to convert the result of (3) from negative to positive.

(5). This is the approximate local mean time of transit.

(6). Write down the longitude of the place converted to time (see page 712).

(7). For longitude East, subtract (6) from (5); for longitude West, add (6) to (5). This gives the G.M.T. corresponding to (5).

To obtain a more accurate result, the calculation is now repeated, using in (8) the value of R for the approximate G.M.T. of transit, $20^h\ 26^m$ on February 10th, instead of that for Greenwich noon.

Circumpolar Stars. Superior and Inferior Transits. Unless the observer be near the equator, there will always be a number of more important stars which are called **Circumpolar** in that they do not "set" but appear to take a circular path round the celestial pole. In Fig. 543 the constellations of Ursa Major, Ursa Minor and Cassiopeia are circumpolar, and choosing any one star, say Alioth in "The Great Bear," this star will follow the path indicated and will be visible both at the **Superior Transit** when it crosses the meridian of the observer, and also at its **Inferior Transit** (as illustrated) when it crosses the meridian 180° distant. Which transit is visible depends, of course, upon the time of year; for instance, at Greenwich, the superior transit of Alioth takes place in daylight during the late autumn and winter.

The example worked out below is for the inferior transit of a star, and the reader should be careful to distinguish between this and the superior one which will take place half a sidereal day (11h. 58m. 02s. mean solar time) earlier or later, In the case of an inferior transit of a north circumpolar star. the star is always due north, though at the superior transit it may be north or south of the observer depending upon his latitude. As shown in Fig. 544 the Local Sidereal Time of the inferior transit is equal to the R.A. of the star plus 12 hours. (See Fig. 534 and explanatory section on page 713).

Thus at the instant of inferior transit:

R.A. star$+$12 hours$=$M.T.P. of transit$+R-$24 hours if necessary. Therefore:

M.T.P. of transit$=$R.A. of star$+$12 hours$-R+$24 hours if necessary.

Example. On November 24th, 1936, in longitude 0° 18′ 00″ East, it is required to find the time of inferior meridian transit of Alioth (Epsilon Ursæ Majoris). The work may be set out as follows:

Date: 1936, November 24.

Longitude . . . . . . $00°\ 18'\ 00''$ E.$=01^m\ 12^s$ E.

R.A. of Alioth	12^h	51^m	14^s		(1)
	12	00	00		(2)
	24	51	14		(3)
R.	04	13	03		(4)
Approx. M.T.P. of transit	20	38	11	November 24.	(5)
Longitude..	00	01	12	East.	(6)
Approx. G.M.T. of transit	20^h	36^m	59^s	November 24.	(7)
R.A. of Alioth	12^h	51^m	14^s		
	12	00	00		
	24	51	14		
R.	04	14	28		(8)
M.T.P. of transit ..	20	36	46	November 24.	
Longitude..	00	01	12	East.	
G.M.T. of transit.. ..	20^h	35^m	34^s	November 24.	

Explanatory Notes on Above Example.

(1). Take from the Abridged Nautical Almanac the Right Ascension of Alioth for November.

(2). Write down 12 hours.

(3). Add (1) and (2).

(4). From the Abridged Nautical Almanac take out the value of *R* for Greenwich noon on November 24th.

(5). Subtract (4) from (3). This gives the approximate local mean time of transit.

(6). Write down the longitude of the place converted into time (see page 712).

(7). For longitude East, subtract (6) from (5) ; for longitude West, add (6) and (5). This gives the G.M.T. corresponding to (5).

To obtain a more accurate result, the calculation is now repeated, using in (8) the value of *R* for the approximate G.M.T. of transit 20^h 37^m on November 24th, instead of that for Greenwich noon.

Method X. Meridian Passage of a Star from Mean of Two Elongations. When following the path of a circumpolar star about the pole, the angular distances which it appears to travel to the east and west of the celestial pole are called the **Elongations.** If the bearings of the star be measured when at its extreme east and west elongation on the same night, the mean of the readings is the bearing of the meridian. The elongations of Polaris are marked E,E in Fig. 543. This is a tedious method at any time, and is useless in the summer since one elongation, at least, will take place in daylight.

A modification of this method is the measurement of the east and west elongation at any given altitude, instead of at the altitude of the pole, the mean of the two elongations on the same night again being the direction of the meridian. Two such points are shown for Dubhe at *e e* in Fig. 543, but owing to the slow change in altitude when the star is near the meridian the method is not to be recommended.

Method XI. Meridian Passage of a Planet. The Right Ascensions for the four navigational planets, Venus, Mars, Jupiter and Saturn are tabulated in the Abridged Nautical Almanac and the transits of these bodies may be observed if required, in order to find the direction of true North. Unlike the case of the stars, the R.A.'s are changing rapidly, and corrections must be made to the R.A. as well as to R for the G.M.T. of transit. The approximate time of meridian passage at Greenwich is, however, tabulated in the Nautical Almanac so that a figure can be obtained for the approximate time of local meridian passage and proper corrections applied without the necessity for preliminary calculation. In other respects the method is identical with that of the stars.

Method XII. Meridian Passage of the Moon. The Right Ascension of the Moon and also the approximate time of Greenwich Meridian Passage are tabulated in the Abridged Nautical Almanac, enabling the local time of transit to be calculated exactly as in the case of the planets. Owing to the size of the moon's disc, it is necessary to observe one limb and to make an allowance for the semi-diameter multiplied by sec. altitude. (See page 729).

Method XIII. Meridian Passage of the Pole Star. From the star map of Fig. 543, and from what has been said on page 737 regarding circumpolar stars, it will be seen that the constellations Ursa Major, Ursa Minor and Cassiopeia all appear to move round the celestial pole once in each sidereal day and a method of finding when Polaris is due North of the observer is as follows. As the star Mizar (ζ Ursæ Majoris) appears to move to a position *vertically under Polaris*, take a sight on these two stars, say with a plumb line (see page 719), note the exact time and write it down. Nineteen minutes later, Polaris will be due North.

The value given for this interval is approximately correct for 1938 and is increasing at roughly half a minute per year. An error of a minute in the time of the observation will, however, make an error in azimuth of the order of only a quarter of a minute of arc.

This is the superior transit of the Pole Star since it is above the pole but the same will, of course, be true at the inferior transit, 12 sidereal hours later, when Polaris is below and Mizar above the pole.

The advantage of the method is its extreme simplicity. No calculation is required, and an error of four minutes of time in judging when Mizar and Polaris are in a vertical plane produces an azimuthal error of only one minute of arc in the bearing of Polaris. The disadvantages, however, are fairly obvious. Since the sidereal day is about four minutes shorter than the solar day, the solar time at which Polaris is on the meridian of the place will alter by this amount each day and for several months in the year, both transits will take place in daylight. In certain latitudes, also, Mizar will be near the zenith at the inferior transit of Polaris, and so cannot easily be observed, but in these cases the star δ Cassiopeiae can be used instead. In Fig. 543 this star is seen to be almost diametrically opposite Mizar, with reference to the pole. If the time be noted when Polaris and δ Cassiopeiae are in a vertical plane, Polaris will be due North after an interval of twenty minutes.

TO FIND THE DIRECTION OF A SHIP'S HEAD

Since all the bearings taken on a ship D.F. are relative to the fore and aft line, it becomes necessary to find the direction of the ship's head before these relative bearings can be converted to true bearings, and this applies equally to bearings taken during calibrating or navigating. The following instructions on the subject may be of use to wireless engineers making ship D.F. trials, although in some cases a navigating officer may volunteer to perform this part of the work, an offer which should be encouraged in Cases III. and IV. below.

Case I. When the Ship is alongside a Quay in any place where reliable Maps are obtainable. The line representing the quayside is found on the map, and its bearing from North measured with a protractor, observing the precautions already stated (page 280), regarding the direction of the meridians on an Ordnance Survey. This bearing will be that of the ship's head, except in the comparatively rare case when she is not parallel to the quay.

Case II. When the Ship is not alongside a Quay, or when for some reason her position only and not the direction of her head can be found from the Map. In this case the bearing of the ship's head may sometimes be found by applying the necessary corrections to the reading of the magnetic compass, these being for variation, which has been mentioned on page 574, and **deviation** which is due to the effects of the magnetization of the iron and steel of the ship. Deviation varies with the direction of the ship's head and, like variation, may be either East or West.

Total Compass Error. The total compass error therefore equals the variation plus or minus the deviation, and before we can obtain true directions from the magnetic compass we must know the value of the variation at the place and the deviation for the position of the ship's head.

If the ship be several miles away from docks, etc., and from other ships the necessary corrections may be made in the following manner.

Ascertain the variation at the place from an Admiralty chart, and the deviation for the position of the ship's head from the deviation table, which generally will be found hung up near the compass to which it refers. Call *Easterly deviations and variations Positive* and *Westerly deviations and variations Negative.* Convert the compass bearing of the ship's head into degrees, as shown below:

Bearings from		Example.	
N to E ..	No change	N39E	39°
E ,, S ..	Subtract from 180° ..	S24E	156°
S ,, W ..	Add to 180°	S53W	233°
W ,, N ..	Subtract from 360° ..	N17W	343°

The algebraic sum of the compass reading, deviation and variation will give the true bearing of the ship's head.

Example.

Ship's head by compass ..	S36°E	(180° – 36°) ..	144°
Variation from chart ..	17°W	(Negative) ..	– 17°
Deviation, from table ..	2°E	(Positive) ..	2°
Ship's head true			129°

Example.

Ship's head by compass ..	N18°W	(360° – 18°) ..	342°
Variation	19° E ..	(Positive) ..	19°
Deviation	2½°E ..	(Positive) ..	2½°
			363½°
			360°
Ship's head true			3½°

Generally speaking, however, it will be found that, owing to the proximity of cranes, warehouses, other ships, etc., the deviation table is unreliable, and then either of the two following methods must be adopted for finding the total compass error.

Case III. Same as II, but where Compass Error is Unknown. Two alternative methods are available, both of which involve the use of the azimuth mirror.

Method I. Obtain a reliable map, on a scale not less than 6″ = 1 mile, of the port in which the ship is lying and the loan of an azimuth mirror from the chief or navigating officer of the ship. Place the azimuth mirror carefully on the bowl of the standard compass and turn the prism by means of the milled head until the arrow is pointing upwards. Rotate the instrument until the pointer, which is seen over the compass card graduation, points to some distant prominent object ashore. Now, on looking down through the prism and slightly adjusting it the object will be seen reflected down on to the compass card. The azimuth mirror should then be moved round gently until the object and the pointer are seen together, and the coincident compass card graduation read off. Care must be taken not to touch the compass bowl or the azimuth mirror at the instant of taking the bearing; that the compass bowl is horizontal; that the compass card is quite steady and not swinging owing to the movement of cranes, etc., in its vicinity, and that the object is exactly coincident with the pointer.

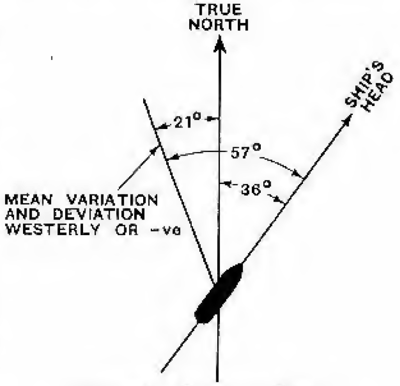


Fig. 545.—Compass Error.

Bearings of three or four such objects in different directions should be obtained and the results carefully noted. The position of the ship must then be fixed and the various objects of which bearings have been taken identified on the map. Pencil lines should be drawn on the map through the positions of the different objects ashore and the position of the ship. Another line should be drawn to represent the meridian through the ship, and from this line the bearings of the various objects may be measured with a protractor. The results may conveniently be tabulated as in the following example:

Example. Belfast, January 18th, 1926.

Ship's position .. Latitude 54° 36′ 30″ N.
Longitude 5° 55′ 00″ W.
Ship's head by compass .. N57E=57°

Object.	Compass Bearing.	True Bearing from Map.	Difference.
Albert clock ..	S59° W=239°	218°	—21°
City Hall	S54° W=234°	213°	—21°
Midland Railway Station	N34° W=326°	304½°	—21½°
B.M. Cave Hill ..	N 5° W=355°	334°	—21°
120-ton crane ..	N79½°E= 79½°	58°	—21½°
Mean difference ..	..	.. ..	—21°

Therefore, total compass error (*i.e.*, variation ± deviation)= —21° and ship's head true=(57°—21°)=36°. See Fig. 545.

Method II. To Find Compass Error from the Sun's Azimuth, using an azimuth mirror and Burdwood's Tables. When the deviation and variation of the magnetic compass are both unknown, the total compass error may be found by comparing the sun's bearing by compass, and the sun's true bearing or azimuth, the operations being exactly analogous to those described in Method III for finding the direction of true North on a shore station. If the sun be visible and his altitude be not greater than 38°, the compass bearing may be obtained by means of the azimuth mirror (see page 742), noting the time by chronometer.

Example. Suppose that in latitude 54° 36′ North and longitude 5° 55′ West on January 18th, 1936, the compass bearing of the centre of the sun's disc was S3½°E. at 9h. 36m. a.m. by chronometer. The error of the chronometer was 29m. 20s. *slow* on G.M.T. It is required to find the total compass error, and hence the true bearing of the ship's head. The work may be set out as follows:

Date: 1936, January 18.

Latitude	54°	36′	00″	N.	
Longitude..	5°	55′	00″	W.=23^m 40^s W.	
Error of Chronometer ..		29^m	20^s	slow.	
Chronometer	09^h	36^m	00^s		(1)
Chronometer error ..	00	29	20	slow.	(2)
G.M.T. and G.D. ..	10	05	20	January 18.	(3)
Longitude..	00	23	40	West.	(4)

M.T.P.	10 29 00	January 18.	(5)
E.	11 49 46		(6)
H.A. of sun	22 18 46		(7)
	12 00 00		(8)
A.T.P.	$10^h\ 18^m\ 46^s$	Janaury 18.	(9)
Declination of sun	20° 44′ South.		(10)
Azimuth of sun	152°·7		(11)
Bearing of sun by compass	176°·5		(12)
Total compass errror	−24° (approx.)		(13)

Explanatory Notes on above Example.

(1) to (5). See same items on page 726.

(6). From the Abridged Nautical Almanac take out the value of *E* for the Greenwich Mean Time and Date (see page 712).

(7). Add (5) and (6). This gives the Hour Angle, expressed in time, of the sun at the time of observation.

(8). This is the 12 hours associated with the equation of time in *E* (see page 712).

(9). Subtract (8) from (7). This gives the apparent time of place.

(10). Take from the almanac the Declination of the Sun for the G.M.T. and G.D. (See definition, page 708).

(11). In Burdwood's Tables find the pages corresponding to latitudes 54° and 55° and *contrary* name (because the latitude is North and the declination South). The A.T.P. (a.m.) will be found on the left of each page, and the A.T.P. (p.m.) on the right. The azimuths are taken out from under the declinations, which are found at the head of each column. The correct azimuth is found by interpolation.

The azimuth so obtained is East of North for a.m., and West of North for p.m. Convert p.m. azimuths to East of North by subtracting from 360°.

(12). Write down the observed bearing of sun by compass, expressed in degrees East of North.

(13). Subtract (12) from (11). This gives the total compass error with its correct sign (see page 741).

Case IV. Ship at Anchor (or Moored). Under these conditions the ship will almost invariably be swinging, and it will therefore be necessary to station someone at the standard compass to note the reading every time a D.F. bearing is taken, communication between the wireless office and the bridge being effected in the same way as when operating the D.F. at sea. It it, of course, necessary that the compass error should be known.

If the ship is in such a position that the compass is still under the influence of cranes, etc., the position of the ship must be found by horizontal sextant angles or by some other means, and the compass error determined by one of the foregoing methods.

TO CALCULATE TRUE, OR GREAT CIRCLE, BEARING AND DISTANCE

In Fig. 546, if A and B are two places on the earth's surface, the latitudes and longitudes of which are known, the angles at A and B and the distance between the places can be found as follows :

$$\tan \frac{B + A}{2} = \cos \frac{l_B - l_A}{2} \cot \frac{D}{2} \ \operatorname{cosec} \frac{l_B + l_A}{2}$$

$$\tan \frac{B - A}{2} = \sin \frac{l_B - l_A}{2} \cot \frac{D}{2} \ \sec \frac{l_B + l_A}{2}$$

where : B is the place of greater latitude, *i.e.*, nearer the pole.
D is the difference of longitude between A and B.
l_A is the latitude of A, and
l_B is the latitude of B

These equations give the values of $\frac{B + A}{2}$ and $\frac{B - A}{2}$ from which we get

$$\frac{B + A}{2} + \frac{B - A}{2} = B \quad \text{and} \quad \frac{B + A}{2} - \frac{B - A}{2} = A$$

In these formulæ north latitudes are taken as positive and south latitudes as negative. For instance, if B is in latitude 50° N. whilst A is in 15° S., then :

$$\frac{l_B + l_A}{2} = \frac{50 + (-15)}{2} = \frac{50 - 15}{2} = \frac{35}{2} = 17° \ 30'$$

$$\text{and} \ \frac{l_B - l_A}{2} = \frac{50 - (-15)}{2} = \frac{50 + 15}{2} = \frac{65}{2} = 32° \ 30'$$

If $l_B + l_A$ is negative, as, for example, when both places are in the southern hemisphere as in Fig. 546 (*c*), it is simpler to call the place of greater *South* latitude B, and to use the above method for giving the bearings from true South and to convert the results afterwards to bearings east of North. In this case south latitudes should be taken as positive and north latitudes as negative.

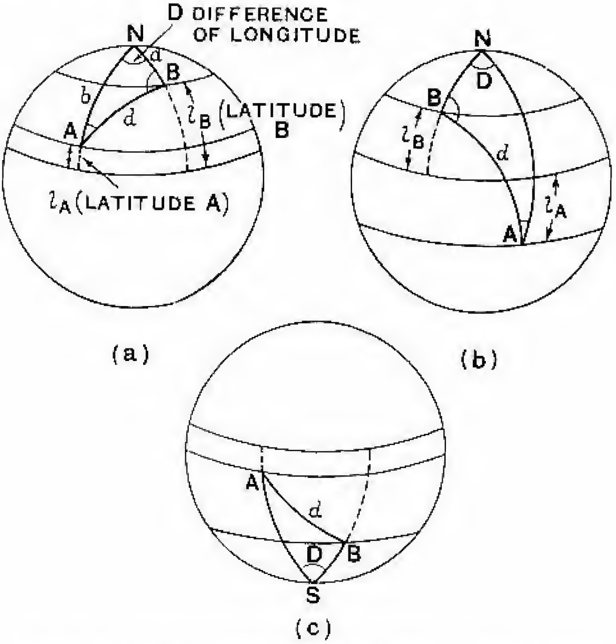


Fig. 546.—Great Circle Angle and Distance by Calculation.

Distance. The equation :

$$\tan\frac{d}{2} = \sin\frac{B+A}{2}\tan\frac{l_B - l_A}{2}\operatorname{cosec}\frac{B-A}{2}$$

gives the value of *d*, the angular distance in degrees between A and B, and this may be converted to linear distance as follows :

d (degrees) × **111·136 = Kilometres.**
× **69·057 = Statute miles.**
× **60.000 = Nautical miles.**

When multiplying, the minutes and seconds of arc must be expressed in fractions or decimals of a degree. If, for instance, $d = 78° 43' 21''$, this must be written as 78·7225 degrees. A table for this conversion is given in the unabridged Nautical Almanac.

Example. Find the Great Circle Bearing and Distance in statute miles of **Perth** (Western Australia), Long. 115° 52′ 45″ E. Lat 31° 57′ 30″ S. from **London**, Long. 0° 5′ 45″ W. Lat. 51° 30′ 30″ N.

	LONGITUDE.	LATITUDE.	
Perth London	115° 52′ 45″ E. 0° 5′ 45″ W.	−31° 57′ 30″ S 51° 30′ 30″ N.	l_s l_n
D =	115° 58′ 30″	19° 33′ 00″ 83° 28′ 00″	(l_n+l_s) (l_n-l_s)

$\frac{D}{2} = 57° 59' 15''$ $\quad\frac{l_n + l_s}{2} = 9° 46' 30''$ $\quad\frac{l_n - l_s}{2} = 41° 44' 00''$

$\frac{B + A}{2} = 70° 00' 10''$	log cos $\frac{l_n - l_s}{2}$	9·872885
	Add log cot $\frac{D}{2}$	9·796000
	Add log cosec $\frac{l_n + l_s}{2}$	10·770115
	log tan $\frac{B + A}{2}$	10·439000
$\frac{B - A}{2} = 22° 53' 37''$	log sin $\frac{l_n - l_s}{2}$	9·823255
	Add log cot $\frac{D}{2}$	9·796000
	Add log sec $\frac{l_n + l_s}{2}$	10·006351
	log tan $\frac{B - A}{2}$	9·625606

$\frac{B + A}{2} + \frac{B - A}{2}$ = B = 92° 53′ 47″ East of North = Bearing of Perth from London

$\frac{B + A}{2} - \frac{B - A}{2}$ = A = 47° 06′ 33″ West of North = Bearing of London from Perth

	log sin $\frac{B + A}{2}$	9·972993
$\frac{d}{2} = 65° 06' 15''$	Add log tan $\frac{l_n - l_s}{2}$	9·950371
	Add log cosec $\frac{B - A}{2}$	10·410027
d = 130° 12′ 30″	log tan $\frac{d}{2}$	10·333391

Linear Distance = 130·2 × 69·057 = 8,991 Statute Miles.

TO PLOT A GREAT CIRCLE ON A MERCATOR'S CHART

On pages 267 onwards, when comparing the properties of the Mercator and gnomonic charts, reference was made to a method of calculating the points of intersection of the great circle between any two points, with the intervening meridians, thereby enabling the great circle track to be plotted on a Mercator or any other chart. The great circle which was taken as an example in Chapter 8, was between the points A 25° N., 15° W., and B 45° N., 15° E., and the method of finding the intersections of this great circle with the meridians 10° W., 5° W., prime meridian, 5° E., and 10° E., is given below as an example of the method.

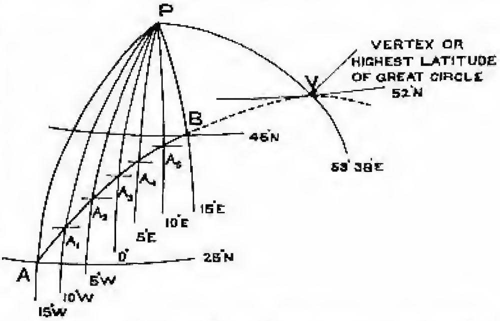


Fig. 547.—Calculation of Intersection of Great Circle AB with Meridians in order to Plot Great Circle on Mercator's Chart.

In Fig. 547 ABV is the great circle and V is the vertex or point of greatest latitude, which may or may not lie between A and B. In this example it lies to the eastward of B. The points A_1, A_2, etc., are the required points of intersection with the meridians.

It is necessary first to solve the triangle APB, in order to find the values of the angles at A and B. This process has been described in the previous problem, and when applied to this example gives A = 42° 47′ and B = 60° 31′ 30″.

The latitude of V must next be found as follows :

> In the spherical triangle APV, of which the angle at V is a right angle, we have :
>
> $\tan P = \cot A \operatorname{cosec} l_A$ where l_A = lat. of A
> $\cos l_V = \sin A \cos l_A$ where l_V = lat. of V.

Solving these equations, we have :

$$
\begin{array}{llrlr}
\text{Angle } A = 42^\circ\ 47' & \ldots \log \cot A & 10{\cdot}03364 & \ldots \log \sin A & 9{\cdot}83202 \\
l_A = 25^\circ \text{ N.} & \ldots \log \operatorname{cosec} l_A & \underline{10{\cdot}37405} & \ldots \log \cos l_A & \underline{9{\cdot}95728} \\
\text{Add} & \ldots \log \tan P & 10{\cdot}40769 & \ldots \log \cos l_V & 9{\cdot}78930
\end{array}
$$

whence P = 68° 38′ and l_V = 52° N.

Now find the longitude of V. The angle VPA = 68° 38′, and since the longitude of A is 15° W., long. V = 68° 38′ − 15° = 53° 38′ E.

The latitudes of intersection of any meridian A_1, A_2, etc., can now be found by solving the triangles PVA_1, PVA_2, etc., in which we have:

$$\cot l_{A_1} = \cot l_V \sec VPA_1, \text{ etc., etc.,}$$

and this is most simply done by tabulating the work as shown below.

The angles VPA_1, VPA_2, etc., may be written down, remembering that the longitude of V is 53° 38′ E., thus :

Angle VPA corresponding to meridian 10° W. is 53° 38′ + 10° = 63° 38′, and so on.

Meridians	10° W.	5° W.	0°	5° E.	10° E.
VPA_1, VPA_2, etc. ..	63° 38′	58° 38′	53° 38′	48° 38′	43° 38′
log cot l_V (52°)	9·89281	9·89281	9·89281	9·89281	9·89281
log sec VPA_1, VPA_2, etc.	10·35251	10·28357	10·22698	10·17988	10·14040
log cot l_{A_1}, l_{A_2}, etc. ..	10·24532	10·17638	10·11979	10·07269	10·03321
Latitudes of A_1, A_2, etc.	29° 37′	33° 40′	37° 12′	40° 14′	42° 49′

TO DRAW A GNOMONIC CHART (GRATICULE)

In Chapters 8 and 14, the characteristics and uses of the gnomonic chart have been described, and on page 263 a series of gnomonic graticules was shown, a simplified diagram of one of these being illustrated in Fig. 445. For the purpose of demonstrating the construction of such a graticule, it is proposed to reproduce all the essential features in the preparation of " Chart F " (Fig. 445), of the above-mentioned series.

The particulars of the chart are as follows :

Northern limit of latitude	62° 30°
Southern limit of latitude	47° 30′
Scale of Chart	25 naut. miles = 1 in.

Point of contact at the centre of the sheet.

The chart thus includes 15 degrees of latitude and with a scale of 25 nautical miles to the inch, the size of the sheet required will be $\frac{15 \times 60}{25}$ = 36 inches (approx.), so that a sheet 40 inches by 40 inches will leave a suitable margin.

A mathematical analysis of the gnomonic projection will be found in the Admiralty Manual of Navigation, but the requisite information is contained in a set of formulæ,* which are numbered 1 to 7 in the ensuing instructions and in which the following symbols are used :

C	Point of Contact.
l_C	Latitude of Point of Contact.
l_a	Latitude of bottom of chart.
l_b	Latitude of top of chart.
G	Difference of longitude between Point of Contact and any given meridian.
R	Radius of the Earth, reduced to scale of chart.
C′	Point of intersection of a' b' by line through C perpendicular to a' b'.
l_c'	Latitude of C′.
l_d	Latitude of parallel through the points d, d', d'', etc.

It should be noted that although the preparation of the data and the instructions for drawing the chart are dealt with together in the following notes, the whole of the calculations may actually be made before any drawing is done, and the advantages of this plan are mentioned later (page 755).

The line *a b* is first drawn to represent the meridian of the point of contact and in the case under consideration this will be at the centre of the sheet, as shown diagrammatically in Fig. 548. The length of line *a b* is given by :—

$$a\,b = \mathrm{R}\,[\tan\,(l_b - l_C) + \tan\,(l_C - l_a)] \quad . \quad . \quad . \quad . \quad (1)$$

and the point C must be chosen such that :—

$$\left.\begin{aligned} b\,\mathrm{C} &= \mathrm{R}\tan\,(l_b - l_C) \\ \mathrm{C}\,a &= \mathrm{R}\tan\,(l_C - l_a) \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

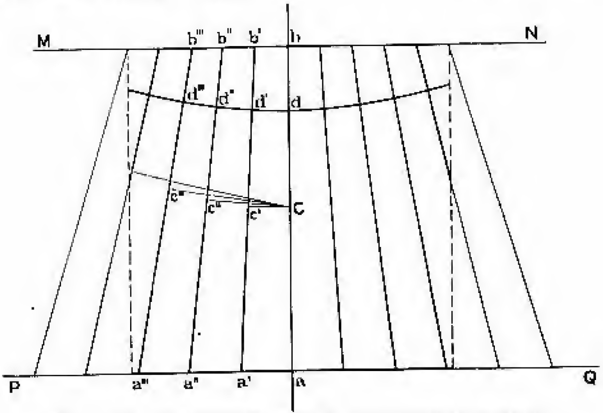


Fig. 548.—Construction of a Gnomonic Graticule.

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In the present case, since the point of contact is at the centre of the sheet, the line *a b* is bisected at C and the length *a b* is therefore given by :—

$$ab = 2R \tan 7^\circ 30'$$

The radius of the earth (20,890, 550 feet), reduced to the scale of the chart is given by $\frac{\text{Radius in feet}}{\text{Scale in feet per inch}} = \frac{20890550}{25 \times 6080}$ and the remainder of the working, using logarithms, is set out below wtihout further comment :—

log 20890550	7·319948
log 25	1·397940
log 6080	3·783904
	5·181844
log R	2·138104

To find *a b* :—

log 2	10·301030
log R	2·138104
log tan. 7° 30′	9·119429
log *a b*	1·558563

$ab = 36{\cdot}188$ inches.

Through *a* and *b*, draw P Q and M N, at right angles to *a b*.

The distances *a a′*, *a a″*, etc., and the corresponding values of *b b′*, *b b″*, etc., must next be found in order to draw the meridians, but before beginning on this it is necessary to decide upon a value for the difference of longitude between successive meridians drawn on the chart. This will depend solely on the accuracy desired, the closer the meridians are together, the greater the number of points available for plotting the curves representing the parallels of latitude. For instance, at the latitude of the point of contact, that is to say 55° N., a degree of longitude is $60 \times \cos 55^\circ = 34{\cdot}2$ nautical miles in length, which is $\frac{34{\cdot}2}{25} = 1{\cdot}4$ inches on the chart. The spacing can therefore be taken as 30 minutes, which will give 0·7 inches between meridians at the centre of the chart and not more than about an inch at the lower margin.

The distances *a a′*, *a a″*, etc., and *b b′*, *b b″*, etc., are found from the following :—

$$aa' = [R \cos l_a \sec (l_C - l_a)] \tan G \quad (3)$$

$$bb' = [R \cos l_b \sec (l_b - l_C)] \tan G \quad (4)$$

The factor contained in the square bracket, by which tan G has to be multiplied, is seen to be a constant quantity in each of the above expressions, and it will simplify the working out of the values of *a a′* and *b b′* for the various values of G, if we find the logarithm of the quantity in the square bracket, in each case, and add this to log tan G., the work being set out in tabular form as in Table I. Note that when C is on the equator, this square bracket expression reduces to R.

Thus, $a\,a' = R \cos 47^\circ\, 30' \sec 7^\circ\, 30' \tan G$.

log R	2·138104
log cos 47° 30′	9·829683
log sec 7° 30′	10·003731
Log of expression in bracket. (See Table I, Col. 3.)	1·971518

and $b\,b' = R \cos 62^\circ\, 30' \sec 7^\circ\, 30' \tan G$.

log R	2·138104
log cos 62° 30′	9·664406
log sec 7° 30′	10·003731
Log of expression in bracket. (See Table I, Col. 5.)	1·806241

TABLE I.

1	2	3	4	5	6
G	Log tan G	Col. 2 + 1·971518	Antilog Col. 3 = *a a′* in inches	Col. 2 + 1·806241	Antilog Col. 5 = *b b′* in inches
0° 30′	7·940858	9·912376	0·8173	9·747099	0·559
1° 00′	8·241921	0·213439	1·634	0·048162	1·117
—	—	—	—	—	—
11° 00′	9·288652	1·260170	18·204	1·094893	12·442
—	—	—	—	—	—
16° 00′	9·457496	—	—	1·263737	18·354

The values in columns 4 and 6 will now enable the distances *a a′*, *a a″*, etc., and *b b′*, *b b″*, etc., to be scaled off along the lines M N, P Q, and the meridians *a′ b′*, *a″ b″*, etc., drawn.

The length, in inches, of C *d*, along the centre meridian, in which *d* is the point of intersection on *a b* of a parallel of latitude, l_d, is found from :—

$$Cd = R \tan (l_d - l_C) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The work may again be tabulated as in Table II, parallels being taken every 30 minutes of arc, as in the case of meridians.

The constant quantity 2·138104, in Col. 4, is the logarithm of R.

TABLE II.

1	2	3	4	5
l_d	$l_d - l_C$	Log tan $(l_d - l_C)$	Col. 3 + 2·138104	C*d* in inches
62° 30′	7° 30′	9·119429	1·257533	18·094
62° 00′	7° 00′	9·089144	1·227248	16·874
61° 30′	6° 30′	9·056659	1·194763	15·659
—	—	—	—	—

Perpendiculars must next be dropped from the point C on to all the meridians, intersecting them at the points c', c'', etc. It should be noted that these points c', c'', etc., do *not* lie on the same parallel (unless C is on the equator), and the actual latitudes of these points are next found from :—

$$\tan l_c' = \tan l_C \sec G. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Table III, below, shows the work set out in columns 1 to 4, the constant which is added in column 3 being the value of $\log \tan l_C = \log \tan 55° = 10{\cdot}154773$.

(The last two columns contain data which is required later but which may very conveniently be tabulated at this stage. The constant which is added in column 6 is explained below.)

TABLE III.

1	2	3	4	5	6
G	Log sec G	Col. 2 + 10·154773	l_c'	Log sin l_c'	Col. 5 + 2·224740
0° 30′	10·000017	10·154790	55° 00′ 06″	9·913370	2·138110
1° 00′	10·000066	10·154839	55° 00′ 15″	9·913387	2·138127
1° 30′	10·000149	10·154922	55° 00′ 30″	9·913409	2·138149
—	—	—	—	—	—

The final problem consists in calculating, from the following :—

$$C'd' = [\mathrm{R} \operatorname{cosec} l_C \sin l_c'] \tan (l_d - l_c') \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

the distance in inches from the point C′, of the intersections of all the parallels. This must be done for each meridian, but it will be seen that the factor in the square bracket is a constant quantity for any given meridian and this series of constants are the values found in column 6 of Table III above.

For the case of C on the equator, $C'd'$ becomes equal to R sec G tan l_d.

Thus Table III, column 5 gives the value of log. sin. l_c' for varying values of latitude and in column 6 is added to this a constant equal to :—

log R .. .. 2·138104
log cosec l_C .. 10·086636
2·224740

A set of tables must now be made for successive values of G (that is, difference of longitude from the meridian of the point of contact). From the symmetry of the present chart, it will only be necessary to make calculations for one half of the sheet. Starting with a value of G = 0° 30′, we get :—

TABLE IV.

G = 0° 30′

1 l	2 $(l_d - l_c')$	3 Log tan $(l_d - l_c')$	4 Col. 3 +2·138110	5 Antilog Col. 4 = $C'd'$
62° 30′	7° 29′ 54″	9·119332	1·257442	18·090
62° 00′	6° 59′ 54″	9·089039	1·227149	16·871
61° 30′	6° 29′ 54″	9·056546	1·194656	15·655
—	—	—	—	—
—	—	—	—	—

TABLE V.

G = 1° 00′

1 l_d	2 $(l_d - l_c')$	3 Log tan $(l_d - l_c')$	4 Col. 3 +2·138127	5 Antilog Col. 4 = $C'd'$
62° 30′	7° 29′ 45″	9·119185	1·257312	18·085
62° 00′	6° 59′ 45″	9·088883	1·227010	16·865
61° 30′	6° 29′ 45″	9·056379	1·194506	15·650
—	—	—	—	—
—	—	—	—	—

Table VI is then made out for G = 1° 30′, and so on, the constants in column 4 being obtained in each case from the last column of Table III.

Table I, when completed, will show the extent to which it is necessary to carry these calculations. For instance, it is found that the limit of longitude on either side of the centre meridian, along the upper margin of the chart (Lat. 62° 30′) is 16 degrees, whilst along the lower margin (Lat. 47° 30′), it is only 11 degrees. The vertical margins of the finished sheet are shown as dotted lines in the diagram of Fig. 548. This means that from the table representing $G = 11° 30'$, to the table representing $G = 15° 30'$, the tables may be made gradually shorter, neglecting the portions of the meridians not included in the finished sheet. A glance at Fig. 548 will make this point clear.

Hints on Drawing the Chart. Good quality cartridge paper must be used for the drawing and the room in which the work is carried out should be kept at an even temperature and humidity. The latter factor is an important one, as if the drawing is started on a damp day and not completed, it may be found on resuming the work on a subsequent dry day, that the paper has shrunk and rendered the whole thing useless, as none of the calculated data will now fit in with the new dimensions. Pasting the edges of the paper on to a drawing board is not a very satisfactory solution as it is difficult to avoid crinkling or tearing the paper, due to expansion and shrinking, and the only safe method is to prepare all the data beforehand, to choose a dry day for the drawing and complete it as rapidly as possible. To ensure complete accuracy, check measurements should be made on the drawing at the time it is lithographed (if this is done) to see that it has not shrunk. It may be pointed out by way of warning that the simple process of tracing the chart and making "blue prints" introduces difficulties as the printing papers used (or at any rate many of the commercial brands), shrink, during subsequent processing, about $\frac{1}{8}$ inch per foot in one direction and very much less than this in the direction at right angles. As a result of this, the finished 40″ square chart will be distorted in one direction to the extent of about $\frac{3}{8}$″ to $\frac{1}{2}$″.

A method of reducing the errors that would result from the use of a normal protractor on a graticule that is distorted in this way, is to draw round the periphery of the graticule a protractor scale the centre of which is at the point of contact. This protractor will then be distorted to the same extent as the graticule and bearings from the point of contact will remain correctly rendered.

It will more commonly be necessary to plot bearings from a point that is near to, but not precisely at, the point of contact. In this case the line, after being drawn in the desired position on the graticule, must be transferred with a parallel rule so as to intersect the point of contact and the bearing then noted on the marginal scale.

The instruments required for the drawing consist of an accurate straight-edge, beam compasses, the usual drawing instruments and a moderately flexible steel rule at least as long as the maximum dimension of the chart, and which is graduated in inches, tenths and twentieths of an inch. Although it is not feasible to measure to a thousandth of an inch from a rule graduated in twentieths, yet it will be found that with the aid of suitable lighting and a small magnifying glass, the nearest hundredth can be estimated quite easily and greater accuracy than this is possible after a little practice. It is therefore worth the while to calculate all dimensions to the third place of decimals. This extreme accuracy may seem rather unnecessary in view of the fact that the average D.F. is only reliable to within say about a quarter to half a degree, but experience shows that comparatively slight negligence in drawing the chart may lead to azimuthal errors quite comparable with the errors in observed D.F. bearings.

Having drawn the centre meridian and marked the positions of the points a, b and C, a geometrical construction should be used to obtain the lines M N and P Q at right angles to a b. Set squares and T-square are not reliable for this, and it requires very careful work with beam compasses to obtain points through which to draw M N and P Q such that check measurements between M-P and N-Q are equal to within the thickness of a pencil line.

The dropping of the perpendiculars from C on to the meridians $a\ a'$, $b\ b'$, etc., must also be performed in the same way by geometrical construction, with the possible exception of the meridians very close to the centre one. Having obtained all the points C, C', C'', C''', etc., a flexible steel rule should be placed on the drawing so as to pass through the points, and if any of them do not appear to lie on the smooth curve, their positions should be checked and corrected.

When all the points on the meridians have been scaled off it is advisable to draw a smooth curve to represent each parallel, using the flexible steel rule, and again any point which is not on this curve should be checked. A number of such slight errors always occur amongst a mass of tabulated calculations.

At this stage a few check bearings should be measured from the chart, the correct values of which have previously been calculated and provided these agree to within a few minutes of arc, the chart can be inked in and completed.

The parallels need not be inked in as curves. If straight lines are drawn between successive meridians, on top of the pencil curve which has already been drawn, the resulting line cannot be distinguished, by eye, from a curve, and it is easier to draw and avoids the chances of smudging when using a

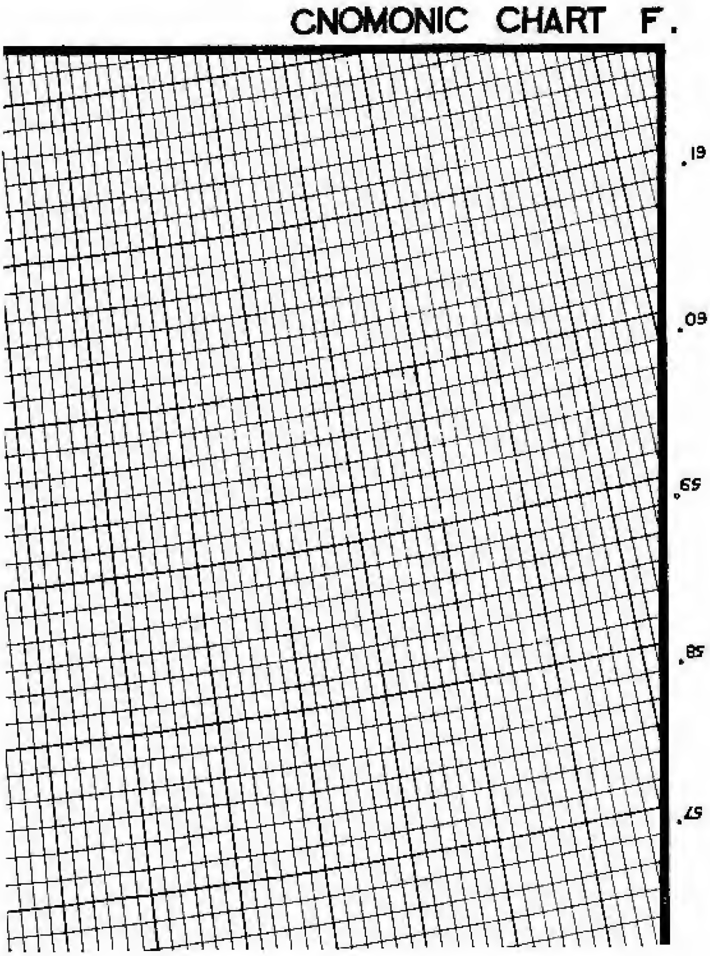

Fig. 549.—Portion of Completed Graticule.

flexible rule. The rule is also rather difficult to manipulate and needs at least two assistants.

For convenience in the use of the chart, it will be advisable to have lines drawn for every 10 minutes of arc, which means that two lines will have to be drawn in each of the spaces between the meridian on the chart and similarly between the parallels. This sub-division entails nothing more than some rather tedious work with a small pair of spring bow compasses. As before, the parallels can be drawn as a succession of straight lines between the points on the meridians and having drawn a border the finished chart will now appear as in Fig. 549, which is a photograph of a corner of the actual chart (reduced to rather less than one-third full size). As already mentioned (page 264), it is convenient to mark the scale of latitude with the numbers upside down in the right-hand margin and make use of the left-hand margin only. By doing this the chart may be turned upside down for use in southern latitudes and the figures in the left-hand margin will still be the right way up.

BIBLIOGRAPHY

Introduction. This list of published articles and papers contains a selection from the literature on Directive Reception and Transmission as applied to navigation. Up to the period, say, 1923-1925, the list is fairly comprehensive and, in addition to accounts of early experimental work, includes some matter that is only indirectly connected with D.F. or that is merely of historical interest. During more recent years, the volume of material published has greatly increased and selection has had to be correspondingly restricted. The bibliography of the subject of Propagation of Electromagnetic Waves alone, for instance, has grown to huge dimensions and only a small proportion of references can be included ; usually when they deal specifically with polarization errors. Here and there publications are included concerning associated subjects such as Maps, Navigation, etc. but the list is confined, in the main, to technical and physical subjects.

Since the book, in addition to being a manual of D.F., aims at being as much use as possible for reference purposes, the items have been numbered in order that they may be quoted, where required, in the text. They have been grouped according to the year of publication, although in a few instances where the discussion on a paper has appeared the following year it has been tabulated under the paper for convenience. With these exceptions the first two figures of the reference number are seen to indicate the year of publication, although the individual items in any year are not necessarily in chronological order.

Dates and Reference Numbers. The above system of numbering the references has the disadvantage that it makes it possible for the numbers for the year 1919 to be themselves mistaken for dates thus ; (1901), (1902), etc. Confusion should not occur, however, as the reference numbers are always enclosed in curved brackets when they occur in the text of the book and the dates have been given square brackets in the columns following, except when they form part of a title.

The full titles of the journals mentioned in Col. 4 will be found on page 786.

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		[1899]			
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2603	Bidwell, C. C.	Direction and Intensity Changes in Radio Waves.	Jour. Frankl. Inst.	201	107
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2613	Blondel, A.	The New French Beacon Stations.	Annales des Postes.T. &T.	15	478
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3407	Green, A. L.	The Polarization of Sky Waves in the Southern Hemisphere.	Proc. I. R. E.	22	324
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3802	Busignies, H.	Reduction of Night Error in Radio Direction-Finding Equipment for Aerodromes.	Elec. Commn.	16	213
3803	Blucke, R. S.	The Practical Use of Radio as a Direct Aid to the Landing Approach in Conditions of Low Visibility.	Jour. Roy. Aero. Soc.	32	483

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ENGLAND

Elect. Eng.	Electrical Engineering.
Engineer.	The Engineer.
Expl. Wireless.	Experimental Wireless.
Jour. I.E.E.	Journal of the Institution of Electrical Engineers.
Jour. Roy. Soc. Arts.	Journal of the Royal Society of Arts.
Jour. Sc. Inst.	Journal of Scientific Instruments.
Phil. Mag.	Philosophical Magazine and Journal of Science.
Proc. Camb. Phil. Soc.	Proceedings of the Cambridge Philosophical Society.
Proc. Roy. Soc.	Proceedings of the Royal Society, Series A.
Proc. Roy. Soc. Arts.	Proceedings of the Royal Society of Arts.
Proc. Phys. Soc.	Proceedings of the Physical Society of London.
Radio Rev.	Radio Review and Wireless Engineer.
Roy. Met. Soc. Jour.	Royal Meteorological Society Journal.
Wireless Wld.	Wireless World.
Year Book of W.T.	Year Book of Wireless Telegraphy and Telephony.

UNITED STATES OF AMERICA

—	Aero Digest.
Aircraft Eng.	Aircraft Engineering.
Bell Lab. Record.	Bell Laboratories Record.
Bell System Tech. Jour.	The Bell System Technical Journal.
Bur. Std. Jour. Res.	Bureau of Standards Journal of Research.
Commn. and Bdcstg.	Communication and Broadcast Engineering.
Elect. Rev. of N.Y.	Electrical Review of New York.
Elect. World.	Electrical World.
G. E. Rev.	General Electric Review.
Jour. Frankl. Inst.	Journal of the Franklin Institute.
Jour. Maryland Acad. Sc.	Journal of the Maryland Academy of Science.
Jour. Wash. Acad. Sc.	Journal of the Washington Academy of Sciences.
Mech. Eng.	Mechanical Engineering.
Phys. Rev.	Physical Review.
Proc. I.R.E.	Proceedings of the Institute of Radio Engineers.
Proc. Nat. Acad. Sc.	Proceedings of the National Academy of Science.
Radio B'cast.	Radio Broadcast.
Radio Eng.	Radio Engineering.
Sc. Pap. Bur. Stand.	Scientific Papers of the U.S. Bureau of Standards, Washington.
Soc. Auto. Eng. Jour.	Journal of the Society of Automotive Engineers.
Terr. Mag.	Terrestrial Magnetism and Atmospheric Electricity.
U.S. Air Comm. Bull.	Air Commerce Bulletin (U.S. Department of Commerce)

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Comptes Rendus.	Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences.
Ecl. Elect.	L'Eclairage Electrique.
Génie Civil.	Génie Civil.
L'Onde Elect.	L'Onde Electrique.
Lum. Elect.	La Lumière Electrique.
Radioélect.	Radioélectricité.
Rev. Générale.	Revue Générale de l'Electricité.
Soc. Internat. des. Elect.	Société Internationale des Electriciens.
T.S.F. Moderne.	La T.S.F. Moderne.

Germany

Ann. der Phys.	Annalen der Physik.
Archiv Elektro.	Archiv für Elektrotechnik.
E.N.T.	Elektrische Nachrichten-Technik.
E.T.Z.	Elektrotechnische Zeitschrift.
Elek. u. Masch.	Elektrotechnik und Maschinenbau.
Ges. Vor. Lilienthal-Gesellschaft.	Gesammelte Vorträge der Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung.
—	Hansa. Deutsche Schiffahrtszeitschrift.
Hochfreq. u. Elektro.	Hochfrequenztechnik und Elektroakustik.
Jahrb. d. Draht.	Jahrbuch Zeitschrift für Drahtlose Telegraphie und Telephonie sowie des Gesamtbietes der Hochfrequenztechnik.
Mitt. Aeron. Obs. Lindenberg.	Mitteilungen des Aeronautischen Observatoriums Lindenberg.
Mitt. Tel. Ver.	Mitteilungen aus dem Telegraphen-Versuchsamt des Reichs-Postamts.
Phys. Zeit.	Physikalische Zeitschrift.
Verh. d. Deuts. Ges.	Verhandlungen der Deutschen Physikalischen Gesellschaft.
Zeit. f. Hochf.	Zeitschrift für Hochfrequenztechnik.
Zeit. f. Tech. Phys.	Zeitschrift für Technische Physik.

Italy

Assoc. Elett. Ital. Atti.	Associazione Elettrotecnia Italiana. Atti.

Japan

Jour. I.E.E. Japan.	Journal of the Institution of Electrical Engineers, Japan.
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Australia

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